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AFML-TR-76-183

AUTOMATED ASSEMBLY FIXTURE DRILLING

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

DECEMBER 1976

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TECHNICAL REPORT AFML-TR-76-183
FINAL REPORT FOR PERIOD MAY 1975 - MAY 1976

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This final report was submitted by Grumman Aerospace Corporation under contract F33615-75-C-5192, Manufacturing Methods Project 806-5, "Automated Assembly Fixture Drilling". Mr. William A. Harris, AFML/LTM, was the laboratory monitor.

This technical report has been reviewed and is approved for publication.

William A. Harris
Project Monitor

For The Director

H. A. Johnson
Chief, Metals Branch
Manufacturing Technology Division

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Drilling	Control Systems	Normality Sensing
Five-Axis Drilling	Numerical Control	Edge Tracking
Automated Drilling	Direct Numerical Control	Edge Sensor
Assembly Fixture Drilling	Computer Control	Programmed Drilling
Fluidic Controls	Computer Numerical Control	Adaptive Sensing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A five-axis, automated assembly drilling fixture was fabricated and implemented in production to drill and countersink holes in aerospace hardware using a movable gantry adapted to an existing A-6E wing outer panel assembly fixture. The drill head, vertical gantry, fluidic controls, and drive systems were designed and fabricated early in the program. Several nosepiece configurations, a normality sensor, and two counter-balance systems were tested and evaluated. Operating parameters for the system were established. Drilling tests were performed on aluminum, titanium, and graphite/epoxy workpieces using high-speed steel and carbide drill/countersink cutters.

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Drill diameters ranged from 5/32 to 5/16 inch. Freon TB-1, Isopar M, water-soluble oil, and water coolants were used. Hole quality was determined by dimensional (diameter) tolerance and surface roughness measurements. Drilling aluminum dry and with a coolant were compared. Eddy current and profilometer readings of drilled-hole surface roughness were correlated. The computer programs required to control multiple drill heads with one computer were developed.

The automated assembly drilling fixture was tested to determine its adaptability to minor position variations of the component substructure. This involved establishment of camera-to-drill relationships and comparisons of the positions of actual camera scans with those of the final drilled holes. Two possible add-on features for the five-axis drilling system that could be used during the drilling cycle were evaluated. One was a thermo-electric adaptive sensing system for feed-rate control and the other was an automatic detector for broken tools.

Several production A-6E wing outer panels were successfully drilled with the automated assembly drilling fixture. The control system and software concepts were proved-out.

PREFACE

This report was prepared by Grumman Aerospace Corporation, Bethpage, New York 11714, under USAF Contract F33615-75-C-5192, Project No. 806-5, "Automated Assembly Fixture Drilling." The work was administered under the technical direction of Mr. William A. Harris (AFML/LTM), Air Force Materials Laboratory, Manufacturing Technology Division, Metals Branch, Air Force Wright Aeronautical Laboratories.

This report covers work conducted from 1 May 1975 to 31 May 1976 and is submitted in fulfillment of the contract. The technical report was released by the author in May 1976.

The program was directed by Mr. William Grauer, Project Manager, Advanced Materials and Processes Development. Others assisting on this program were Mr. Armand Small, Mr. William Peterson, and Mr. William Spratt of Advanced Materials and Processes Development, Mr. Richard Romaneck of Ground Test Instrumentation, and Mr. Larry Lagin of Quality Control.

This project has been accomplished as a part of the Air Force Manufacturing Methods Program, the primary objective of which is to develop on a timely basis manufacturing processes, techniques, and equipment for use in economical production of USAF materials and components.

Your comments are solicited regarding the potential utilization of the information contained herein as applied to your present and/or future production programs. Suggestions concerning additional manufacturing methods development required on this or other subjects will be appreciated.



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SECTION I

INTRODUCTION

A. BACKGROUND

A significant factor in the fabrication of aircraft structures is the cost encountered in preparing holes to accept the wide variety of fasteners used. The large number of holes involved (250,000 to 400,000 for a fighter aircraft and one to two million for bomber and transport aircraft) has made this manufacturing task a major production cost area. Over the past 20 years, major improvements have been made in automating various processes in the aerospace industry. Drilling of subassemblies can be accomplished with automatic drilling and riveting equipment which can drastically reduce manufacturing costs (Fig. 1). Unfortunately, a major portion of the drilling must be performed in assembly fixtures on the production floor. These drilling operations are still performed manually because the equipment and controls required to realize the potential economic benefits of an automated system have just now been developed. The system must be capable of operating in five axes of motion to drill contoured skins and be able to automatically adjust for minor variations in understructure positioning.

The concept of an automated assembly fixture drilling system is truly generic. Such a system could reduce manufacturing costs on composite and metal structures for both large and small aircraft at production and rebuilding facilities. The most apparent approach to the problem of automating assembly drilling operations is to build a multiaxis numerically controlled or computer-controlled drilling work station. However, this is a

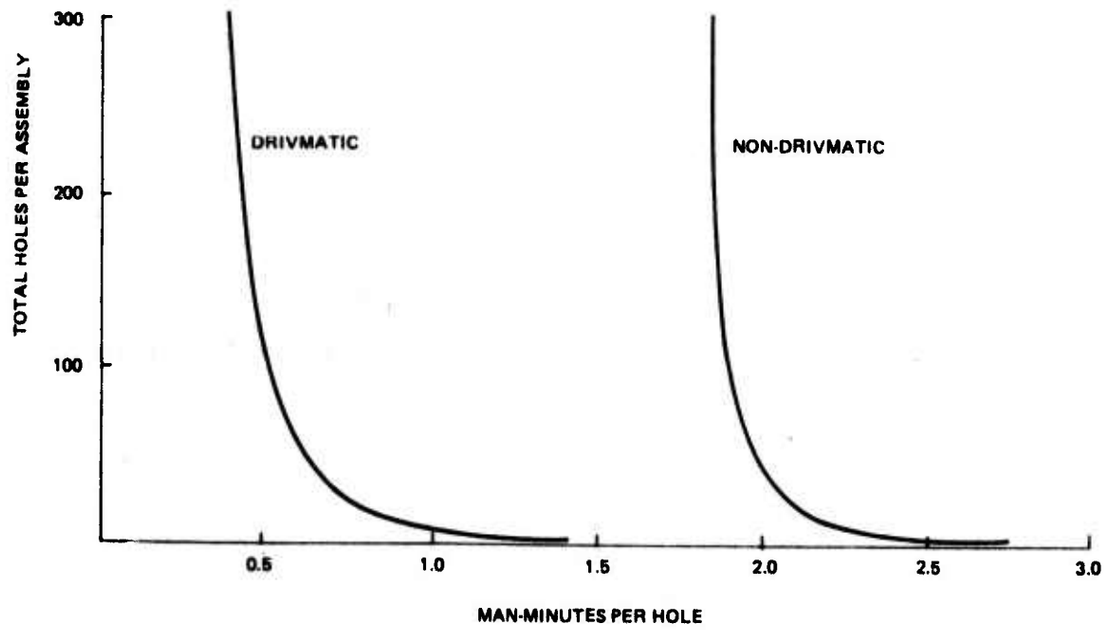


Figure 1. Productivity – Drivmatic vs Non-Drivmatic

superficial answer for aircraft structure drilling since it, in itself, would not compensate for variations in actual structure position. It would require a complex programming system and is a major piece of capital equipment that would be severely under-utilized since there are many non-drilling operations required in such an assembly fixture. These factors, coupled with the trend in recent years for aircraft to become more sophisticated with hundreds of thousands of holes and relatively low production rates, has economically eliminated the practicality of such specialized high-cost equipment.

B. OBJECTIVES

The objectives of this program were:

- To reduce the number of manhours required to perform manual assembly drilling operations in aircraft manufacturing and depot rebuilding
- To keep the cost of capital equipment for performing this program at a minimum to assure realistic economic benefits
- To provide a capability to assure proper structural integrity.

C. SCOPE

This program consisted of the following major tasks:

- Phase I - Automated Drill Head Development. The basic parameters and requirements were established, including operating conditions, angular motion limits, vertical transfer carriage configuration, and assembly fixture modifications. The overall design was directed toward a modular unit concept
- Phase II - Control System Requirements. The position control system for five axes of motion was established. This included necessary interfacing with a mini-computer capable of directing several units, a scan system capable of providing automatic adjustment for minor variations in the aircraft structure, and the necessary software and programming to direct the control system
- Phase III - Evaluation of System. Quantitative data were established on the operating parameters and limits of the system. This evaluation included adaptive sensing for rapid advance, effects of materials, coolants, tolerances relative to software and control system performance, and fixture hole quality.
- Phase IV - Demonstration and Cost Analysis. The total system was demonstrated on an A-6E wing outer panel (Fig. 2). The system demonstrated the features stated in Phases II and III. System costs were identified in modular form and cost tradeoffs made relative to conventional methods.

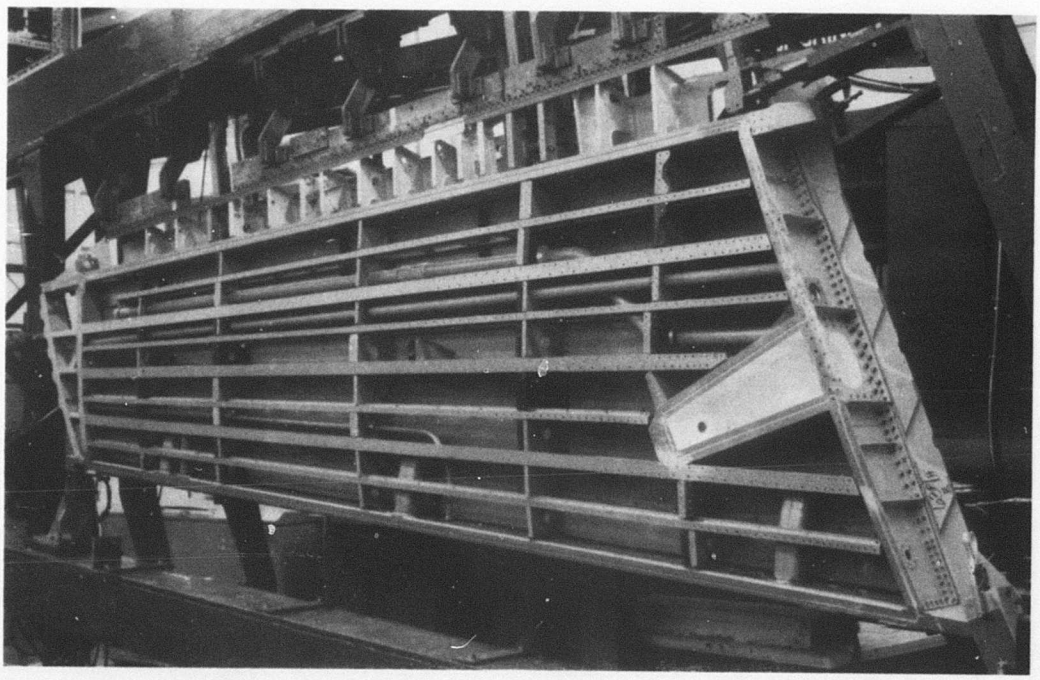


Figure 2. A-6E Wing Outer Panel

SECTION II

AUTOMATED DRILL HEAD

A. OPERATING PARAMETERS

Operating parameters for the drill head and vertical gantry were established. These include fixture control ranges and drive system velocities for each of the five axes, stepper motor-encoder pulse relationships, advance and retraction times for the Z-axis annular cylinder, and drilling and movement times.

1. Control Ranges

The control ranges shown below are sized for the present A-6E wing structure. These dimensions, which are basically a function of fixture size, can be modified to fit most fixtures.

Axis	Control Range	Drive System Velocity
X (length)	206 in.	130 in./min
Y (height)	66 in.	120 in./min
Z (depth)	8-3/8 in.	84 in./min
Alpha (up/down)	9 deg from center*	78 deg/min
Beta (left/right)	9 deg from center*	98 deg/min

*The scan camera and drill unit axis is located in the center of the pneumatic, annular cylinder which controls Z-axis motion. The angle of the camera/drill axis from the Z-axis can be varied by the stated amount.

2. Stepper Motor Control

The X, Y, Alpha, and Beta axes are driven by stepper motors having 200 steps per revolution. The X- and Y-axis stepper motors are coupled through a gear box and driven by a pinion gear-rack arrangement. The X and Y encoders have separate precision racks. The Alpha- and Beta-axis stepper motors drive a ball screw. The Alpha and Beta encoders are coupled identically. The encoder outputs for the four axes of motion are used for display purposes and computer monitoring. The relationship between the motor steps, travel, and encoder pulses is as follows:

Motor Steps	Travel	Encoder Pulses (Encoder Pulses per Rev)
X and Y - 1018.64	1 In.	1000 (2000)
Alpha - 190.85	1 Deg	190.85 (200)
Beta - 183.88	1 Deg	183.88 (200)

3. Z-Axis Pneumatic Annular Cylinder Control

The Z-axis pneumatic annular cylinder retracts and advances for each hole to be drilled so that the nosepiece is not dragged against the skin surface. This cylinder is also programmed to retract further, when necessary, to clear Cleco fasteners or other obstructions. Cylinder operating parameters are as follows:

- Piston area - 31.27 sq in.
- Nominal operating pressure - 20 psig
- Pressure exerted by cylinder on workpiece with hydrocheck locked up - 280 lb
- Pressure exerted by cylinder without hydrocheck - 500 lb.

Although the hydrocheck hydraulically stops the annular cylinder, the cylinder must touch the workpiece before the hydrocheck is actuated. Residual pressure is useful for clamping the skin to the understructure. During the scanning operation, the computer signals the hydrocheck to stop the cylinder at the required camera focal distance from the substructure.

4. Drilling Time

The average drill cycle time for the A-6E wing is as follows:

Operation	Time, sec
Z-Axis Advance (Pneumatic Annular Cylinder)	2.0
Drilling (0.190-in.-dia drill at 2750 rpm and 0.004 ipr)	5.0
Annular Cylinder Retraction	2.1
Move to Next Hole	2.5
Total	11.6

5. Camera Control

The amount of reflected light measured at the Reticon camera lens position with the workpiece located 3.5 in. from the lens is as follows:

Position	Light Intensity, foot - candles
Workpiece Fully Covering Opening*	2,000
Workpiece Covering One-Half Opening*	1,000
*Workpiece given yellow-green polyurethane coating per MIL-C-27725	

6. Acceleration and Deceleration Rates

The rates of acceleration and deceleration of the X- and Y-axis stepper motors (Fig. 3) are set empirically to an optimum point. However, the point at which the motor begins to decelerate is controlled by the computer. This point is set to be 2 in. from the target point if the total distance traveled (D_T) is 4 in. or greater. If total distance traveled is less than 4 in., the deceleration distance is one-half the traveled distance. This is programmed on the computer by the "run time software". Figure 4 gives the X, Y, Alpha, and Beta distance (angle) versus time curves for the fixture.

7. Drill Units

The drill units are the most basic modules in the system. These units are easily interchanged with the camera in the drill head assembly and have their own integral power feed mechanisms. The Rockwell Model 31L-800 and Quackenbush QDP-15 drilling units are used in the automated fixture. The Rockwell unit is available with spindle speeds from 450 to 5000 rpm, an adjustable air/oil feed system, an auto-retract, and an end-of-cycle pneumatic signal for interfacing into the control system. The Quackenbush portable tool is available with a range of spindle speeds from 160 to 3000 rpm and an auto-retract. The wide range of feeds and speeds available in these drilling units makes the automated drilling fixture highly versatile for drilling and countersinking many materials.

B. AUTOMATED DRILLING HEAD ASSEMBLY

The drill head provides Y-axis motion along the vertical transfer carriage and the α and β angular motions for the drill unit and scan camera. This assembly is a basic module in the system and is readily interchangeable between vertical transfer carriages for maximum utilization (Fig. 5). The module uses a rack-and-pinion drive system for the Y-axis motion with a precision rack for use by the encoder.

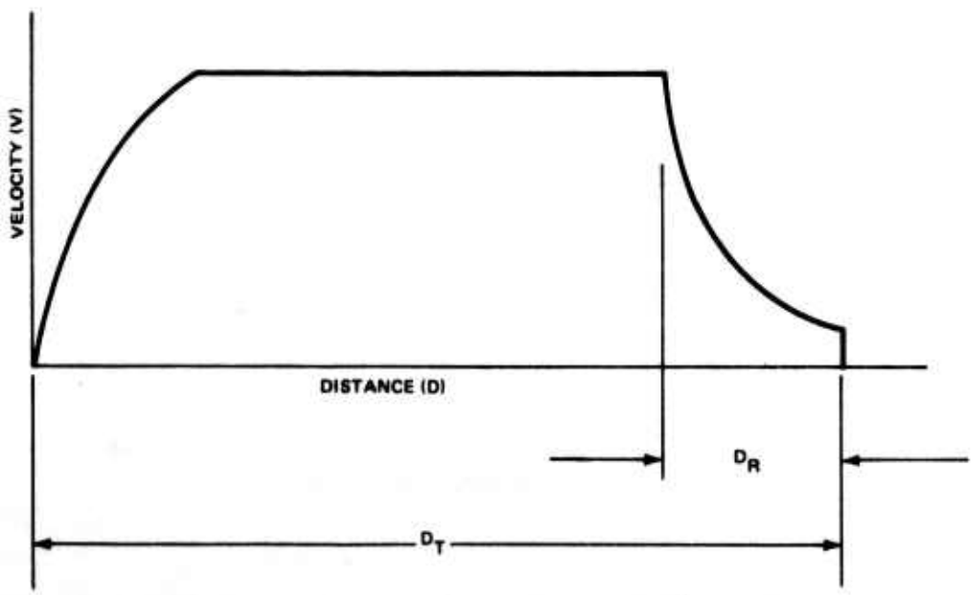
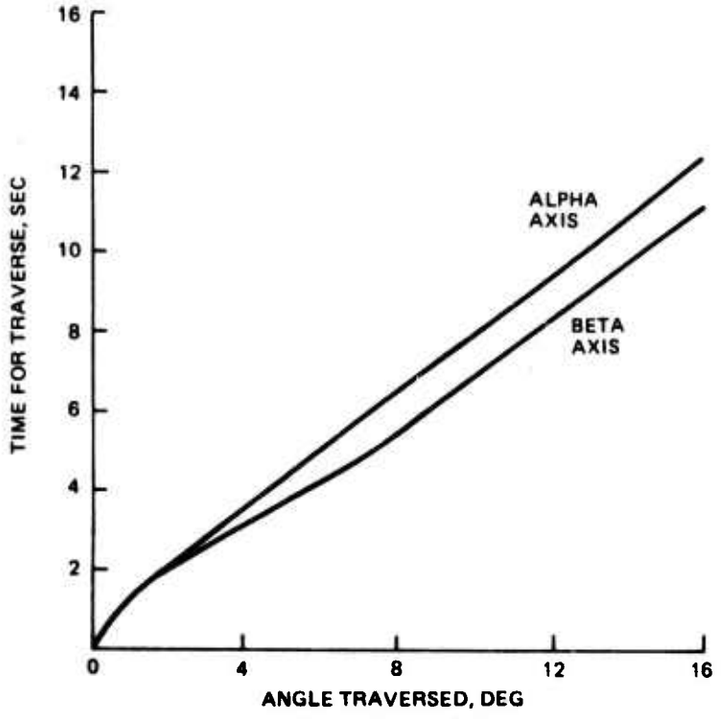


Figure 3. Acceleration and Deceleration Rates for X - and Y - Axis Stepper Motors



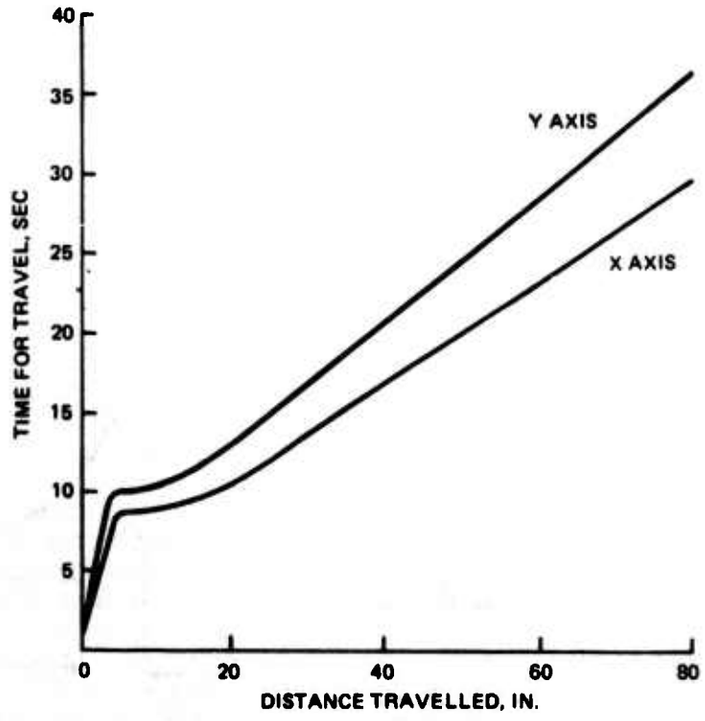


Figure 4. Distance vs Time Curves

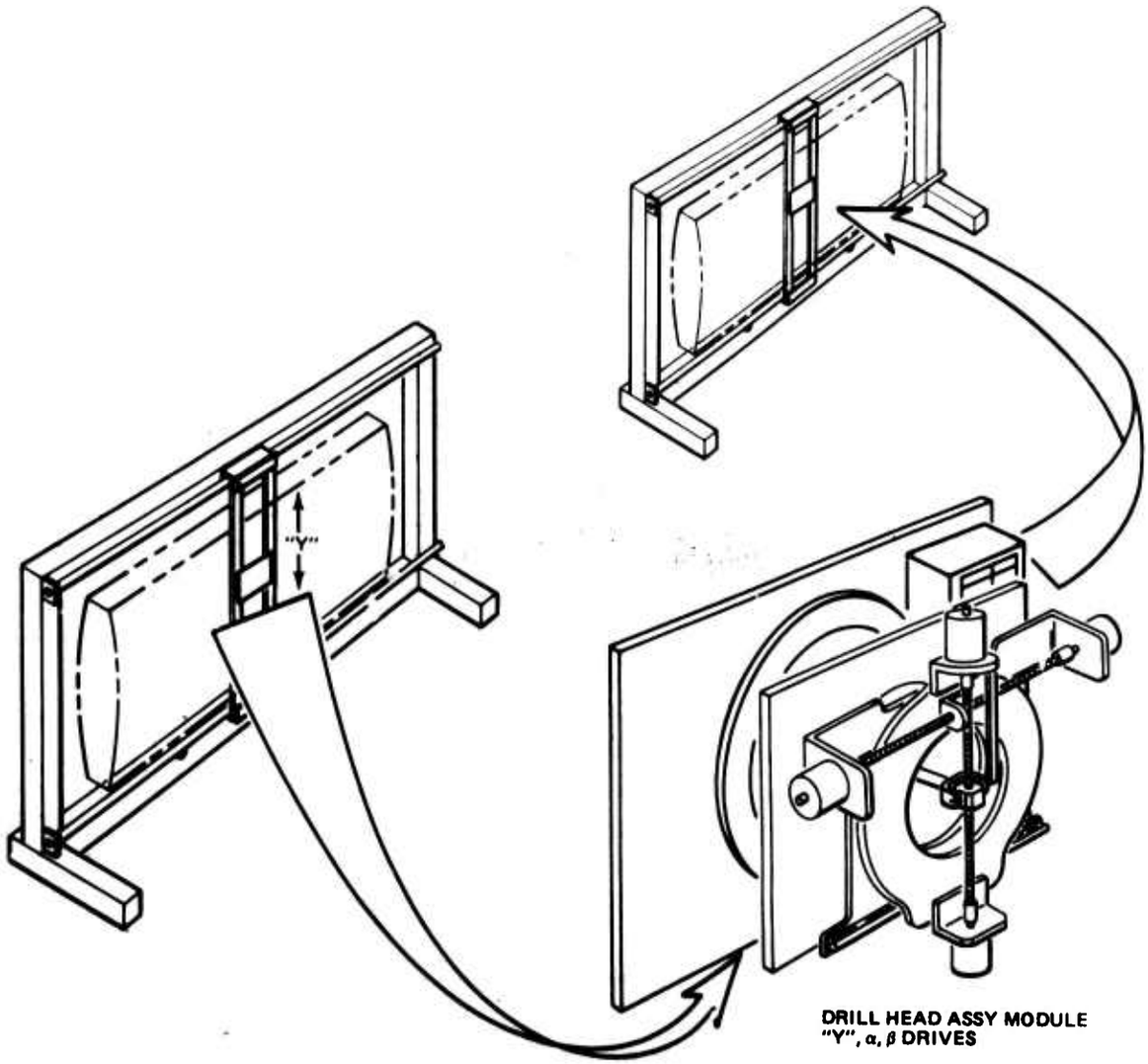


Figure 5. Drill Head Assembly Module

The automated drilling head assembly is capable of being automatically controlled for drilling compound contoured surfaces. Maximum angular displacement of $\pm 9^{o}$ is accomplished by use of an annular piston/cylinder and spherical bearing in the piston head as shown in Fig. 6. The annular cylinder provides the necessary Z motion perpendicular to the X and Y planes of motion. The actual drill head assembly is shown in Fig. 7. The spherical bearing in the piston allows the required angular displacement to permit drilling normal to the contoured surface. Angular displacement of the drill tip is obtained by an X-Y plotter mounted at the rear of the cylinder (Fig. 8). The purpose of having the spherical bearing move along the Z-axis is to permit the angular motion pivot point to be at a minimum distance from the point of drill entry into the workpiece. Ideally, if this distance were zero, the error incurred in the X and Y position would be zero and would no longer be a function of the angular position error. In addition, the practical boundary condition necessitates keeping the "foot-print" or interference zone of the machinery at a minimum in the drilling area. Consequently, the pivot is held to a minimal distance from the surface to ensure insignificant X or Y-axis movement due to slight angular errors (see Subsection IIID).

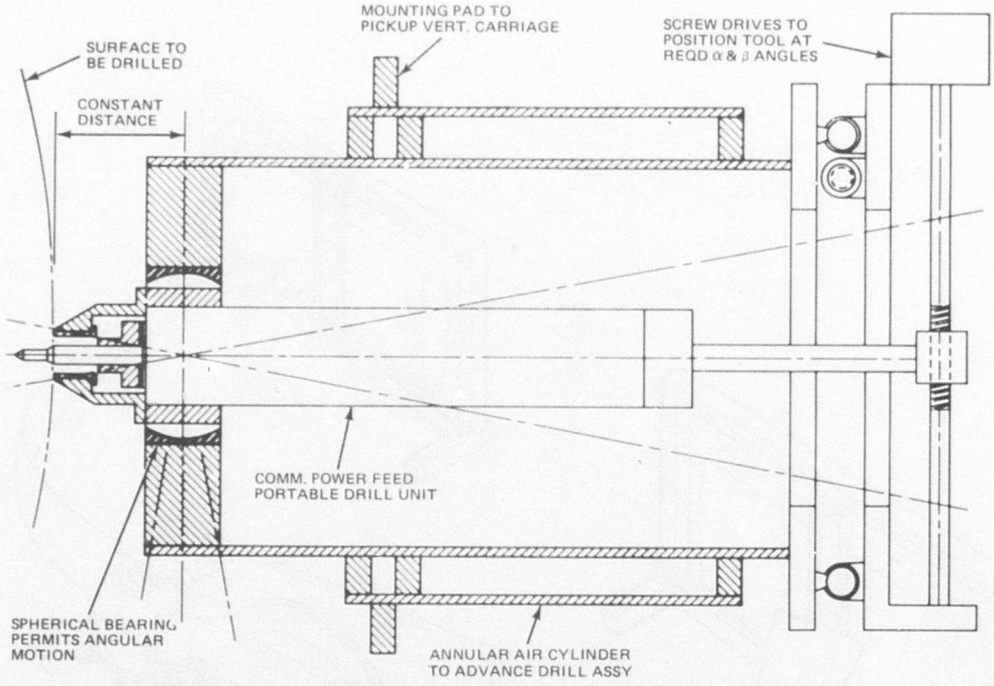


Figure 6. Drill Head - Cutaway View

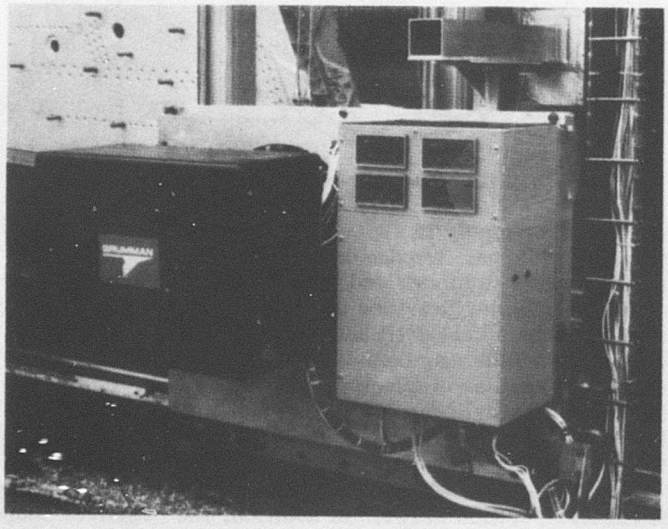


Figure 7. Drill Head Assembly

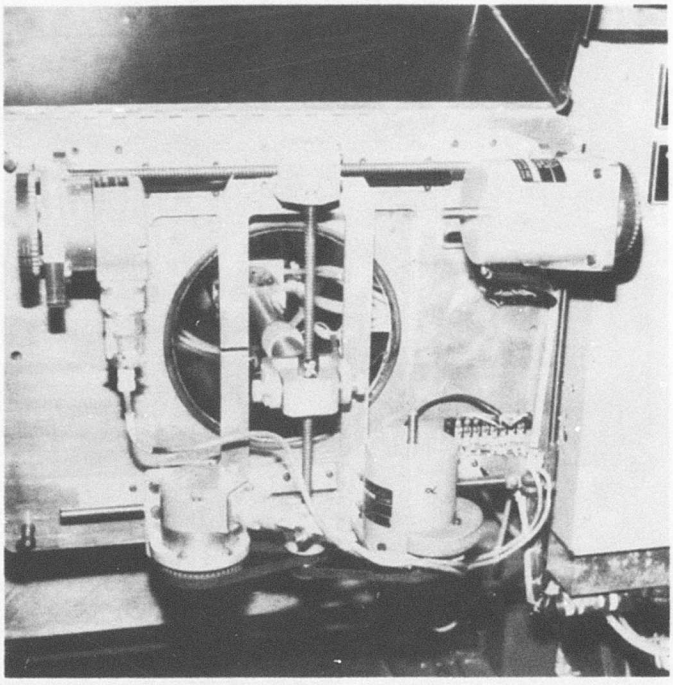


Figure 8. X-Y Plotter

C. VERTICAL TRANSFER CARRIAGE

The vertical transfer carriage or gantry (Fig. 9), the largest module in the system, holds the guideways and basic structure for the drill head assembly Y motion. It is a modular unit which can be moved to an aircraft assembly fixture as needed. A rack-and-pinion drive system is used with a separate smaller precision rack to drive the position feedback encoder. The option of using a precision ball screw was considered but, based on earlier laboratory prototype units, was discarded as unnecessarily costly (about eight times more costly than a rack-and-pinion drive). This can become quite significant on larger aircraft assemblies. A counter-balance system was required to offset the weight of the drill head assembly to permit proper control of ±Y direction accelerations and velocities.

The drill head assembly weighs about 450 lb. Tests were run comparing a commerical counterbalance system with an air drive to a counterweight system. The counterbalance system, besides costing more initially, requires adjustment, maintenance, and an air supply. Tests showed it to be very sticky. The counterweight system adds more inertia to the system but runs very smoothly. In addition, no room is sacrificed and the weights are conveniently hung inside the 4-in.-square steel tube vertical supports. No maintenance or air supply is required.

Vertical Thomson roundways (guideways) were installed on the vertical transfer carriage. These 12-ft-long ways were spaced 2 ft apart and were bonded to the support structure with Hysol FA-934 epoxy adhesive. This method of attachment appears to be a less

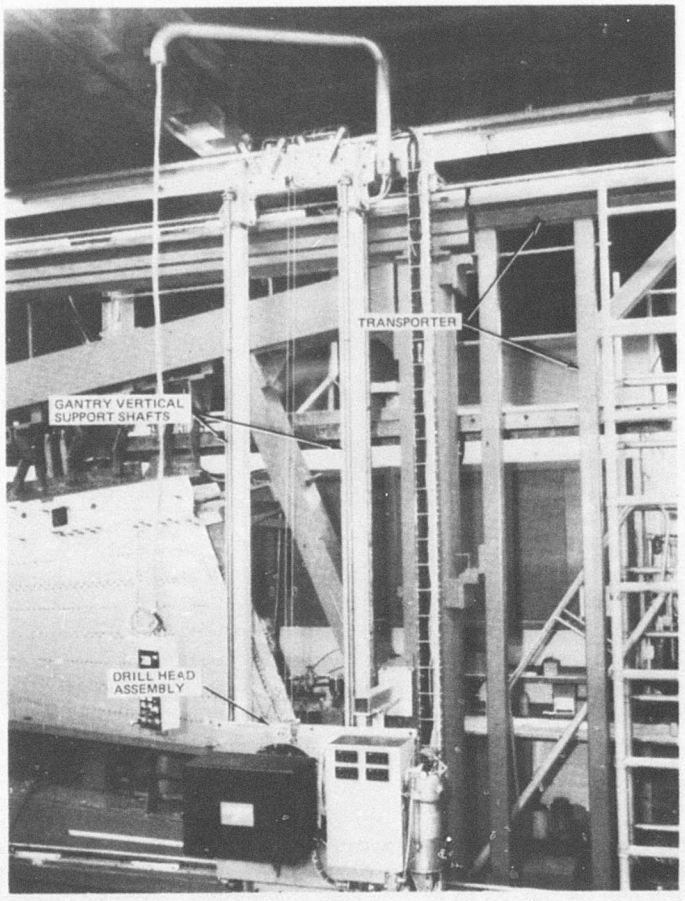


Figure 9. Vertical Transfer Carriage

costly and faster operation than mechanical bolting (Fig. 10). The support structure was bonded to a flat steel plate welded to 4-in.-square commercial steel tubing. The precision rack for the encoder was also bonded to the steel plate. The drill head rides on the vertical roundways using four Thomson ball bushings.

The vertical transfer carriage in its entirety was designed to be transferred as a module to another assembly fixture with identical spacing of the horizontal rails. This was accomplished by driving the vertical carriage off the assembly fixture onto a special detachable extension, the transporter, which could be moved to a different assembly fixture after fluid and power lines were disconnected (Fig. 11).

A brake was designed and fabricated to lock up the vertical transfer carriage when it is in position to drill a hole. A four-way solenoid valve is powered to send 90-psig air to a 1.5-in.-diameter cylinder as soon as the computer signals the start of the drill cycle (Fig. 12). The cylinder drives a wedge which causes a scissor clamping action on the bot-

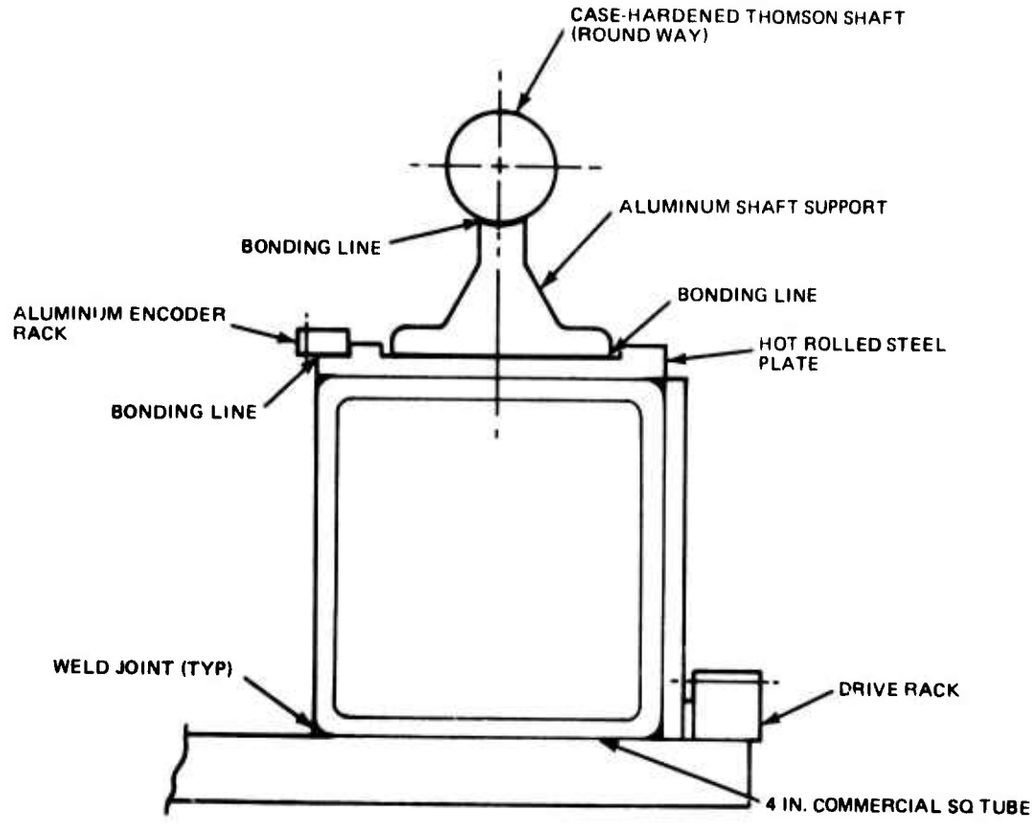


Figure 10. Cross-Section of Vertical Shaft Showing Bonded Joints

tom rail of the automated fixture (Fig. 13). As soon as the countersink is finished, a fluidic signal interrupts the power to the solenoid valve, sending air to the other side of the cylinder to release the clamp. The brake holds the carriage motionless during the drilling cycle.

D. LONGITUDINAL DRIVE SYSTEM

The longitudinal drive system was designed and installed on an existing A-6E aircraft assembly fixture. Each aircraft assembly fixture modified to accept the automated assembly drilling vertical transfer carriage requires upper and lower ways, a drive rack, and a horizontal power track to carry the fluid and power lines, an electrical power pack and a set of electrical and pneumatic cables.

The top and bottom guideways or roundways were bonded to the aluminum shaft support as in the vertical carriage (Fig. 10). Because of the leveling process required, the shaft support, drive, and encoder racks were bolted to the plate.

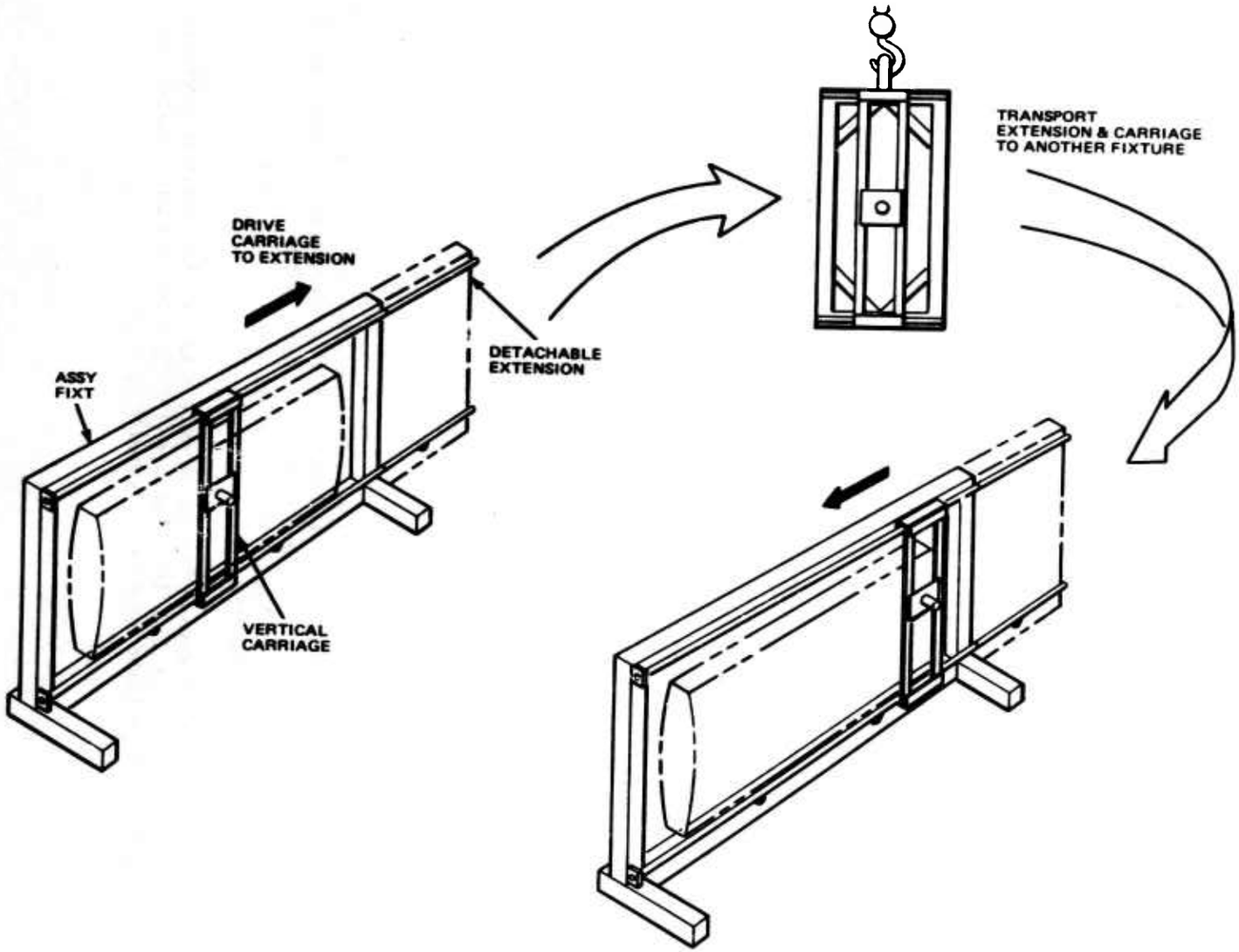


Figure 11. Vertical Carriage Module Concept

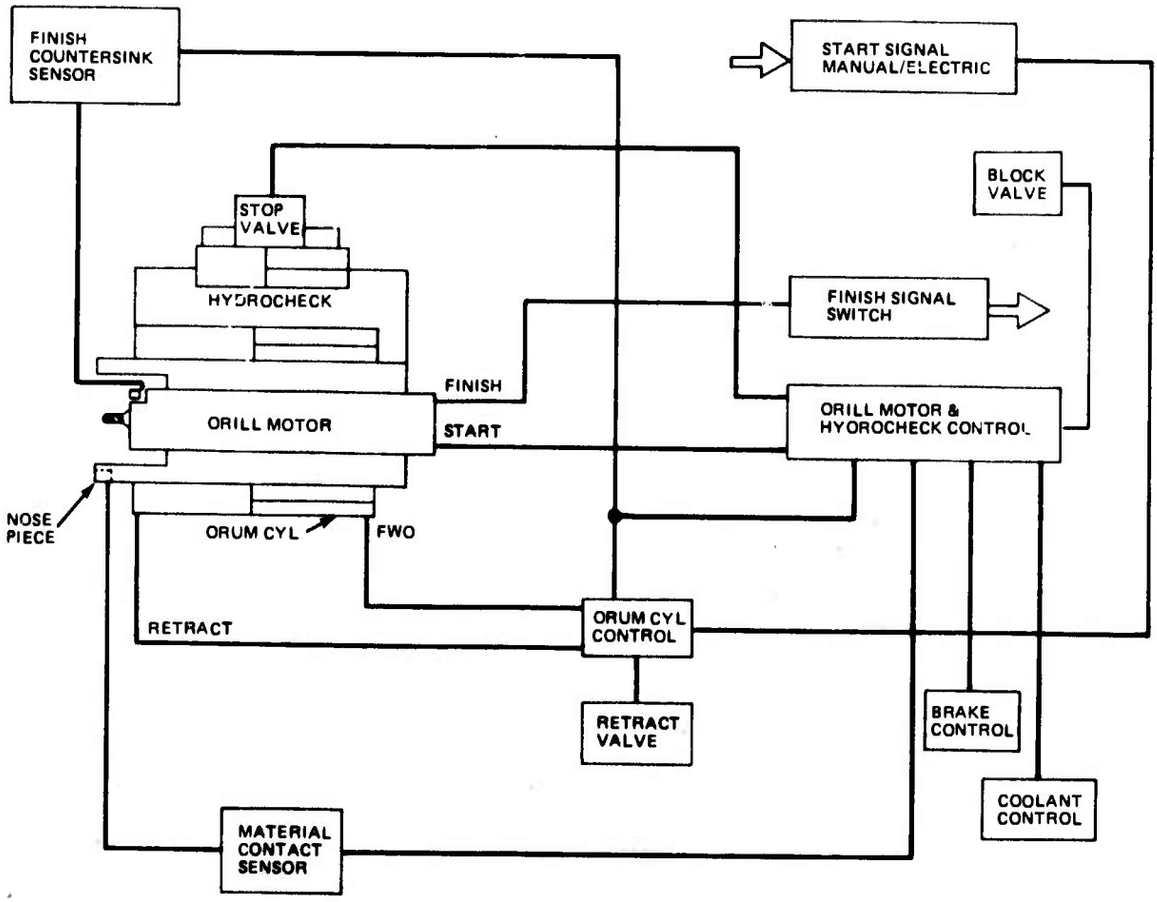


Figure 12 Simplified Fluidic Schematic

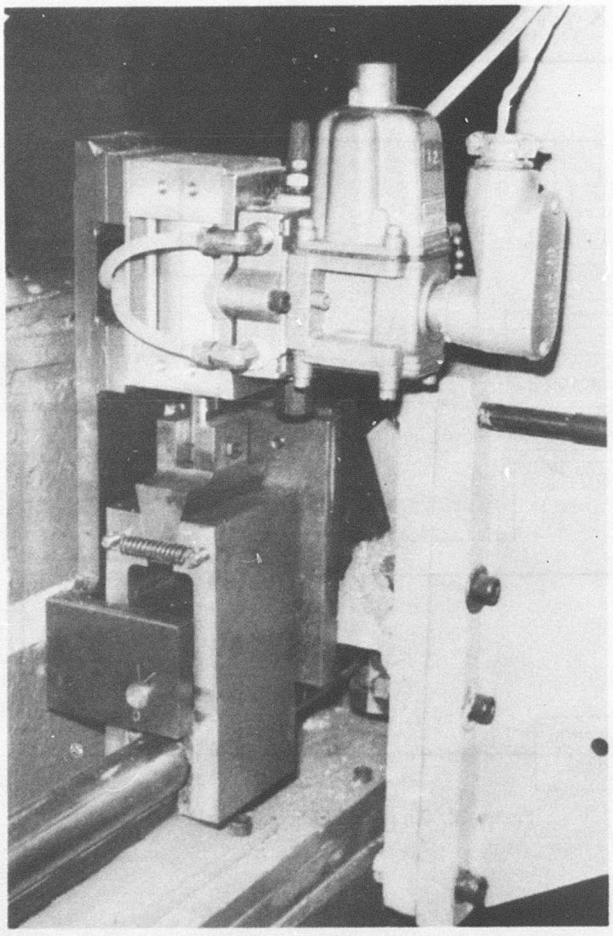


Figure 13. Vertical Transfer Carriage Brake Installation

Section III

CONTROL SYSTEM REQUIREMENTS

A. EVALUATION OF CONTROL SYSTEMS

Two control systems were installed and evaluated. The first was a dedicated minicomputer-based system (Fig. 14) capable of operating one drill unit. This system, which consisted basically of a computer, disc storage, scan camera controller and interface electronics to the frill head and motor drives, operated in a computer-interrupt mode and most of the man-machine interfacing was provided by a teletype. Evaluation of this system showed that it operated very well. The high equipment cost and use of the teletype as the communications medium, however, proved to be disadvantageous.

The second control system was designed to reduce the equipment cost and to enable the operator to completely control the drill unit from a control pendant. A reduction in the equipment cost was brought about by making it possible for the computer and the associated disc storage to simultaneously control up to eight drill units each operating at its own rate on a different part. The interface electronics was moved to a remote interface box located at each gantry to be controlled. A high-speed, serial data link was used to tie the computer to the remote interface boxes. Although some additional hardware was required, the total cost was reduced when three or more units were controlled. Communication to and from the computer was accomplished by an expanded-capability control pendant that allowed the operator to send commands by pushbutton and decade switches. Communications from the computer were transmitted to the operator primarily through a self-scan display that would present a message containing up to 32 alphanumeric characters in a steady mode or a longer message in the scan mode.

The recent introduction of microprocessor systems that emulate the operation of a TDP-8 computer now makes it possible to incorporate a microprocessor at each remote interface box and to use the central minicomputer to handle the transfer of data to and from the disc. This would preserve most of the software already written and substantially reduce the amount of remote interfaces electronics required.

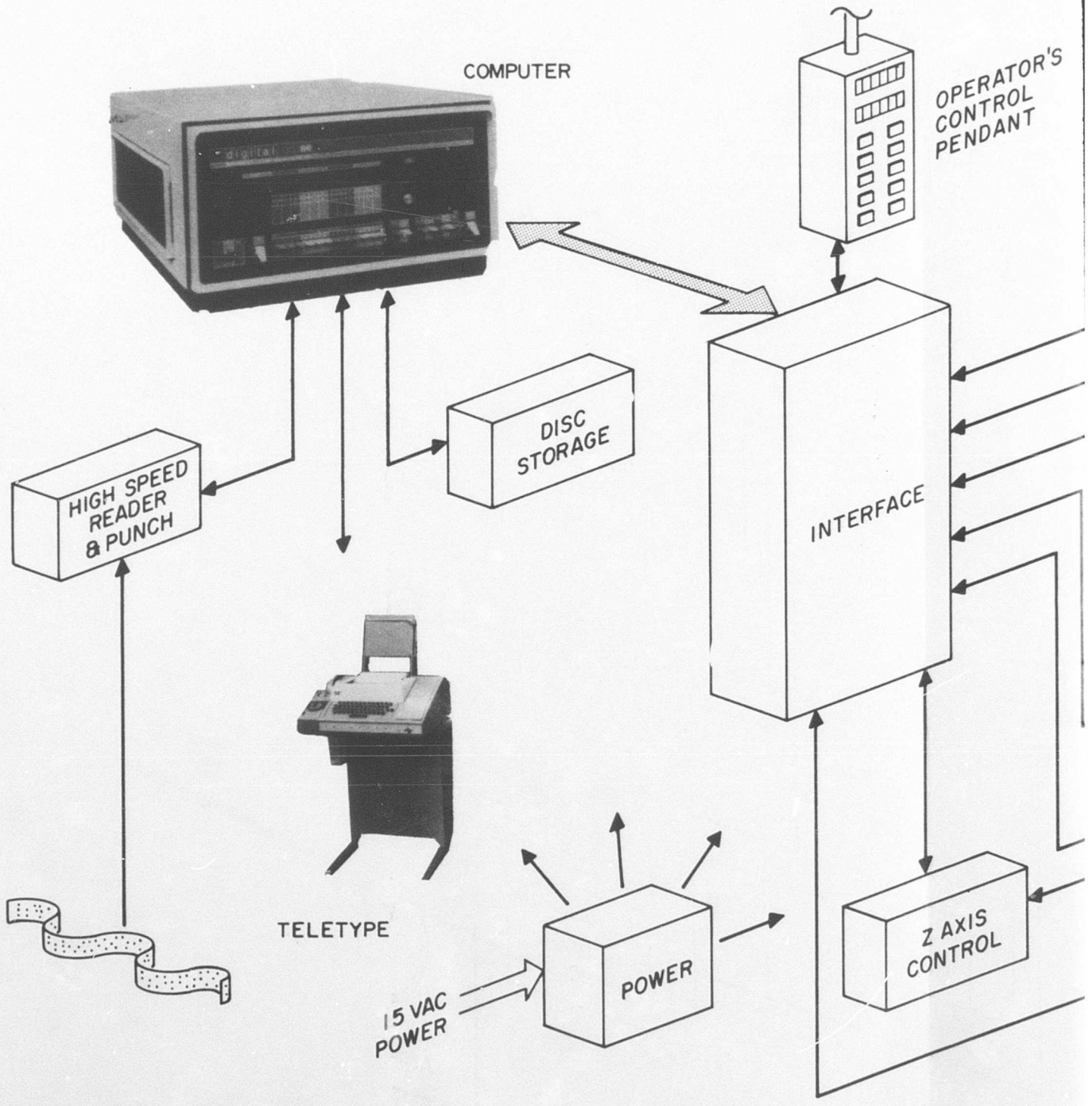
B. SEQUENCE OF EVENTS

The control system is responsible for driving the scanning camera to the target position during the scanning task, modifying the engineering-generated hole coordinates based on the scan readings, and driving the drill to the proper hole position during drilling.

The control system for the automated assembly modules is outlined in the flow diagram (Fig. 15). The sequence of events for the scan cycle flow is listed below:

1. A data file is created on the disc which defines nominal hole position and provides data for scan and drill operations

2. At the start of the scan cycle, the scan camera is inserted into the head assembly and scan position data is sent from disc to computer in blocks of 24 hole positions


COMPUTER
OPERATOR'S CONTROL PENDANT
DISC STORAGE
HIGH SPEED READER & PUNCH
INTERFACE
TELETYPE
POWER
115 VAC POWER
Z AXIS CONTROL

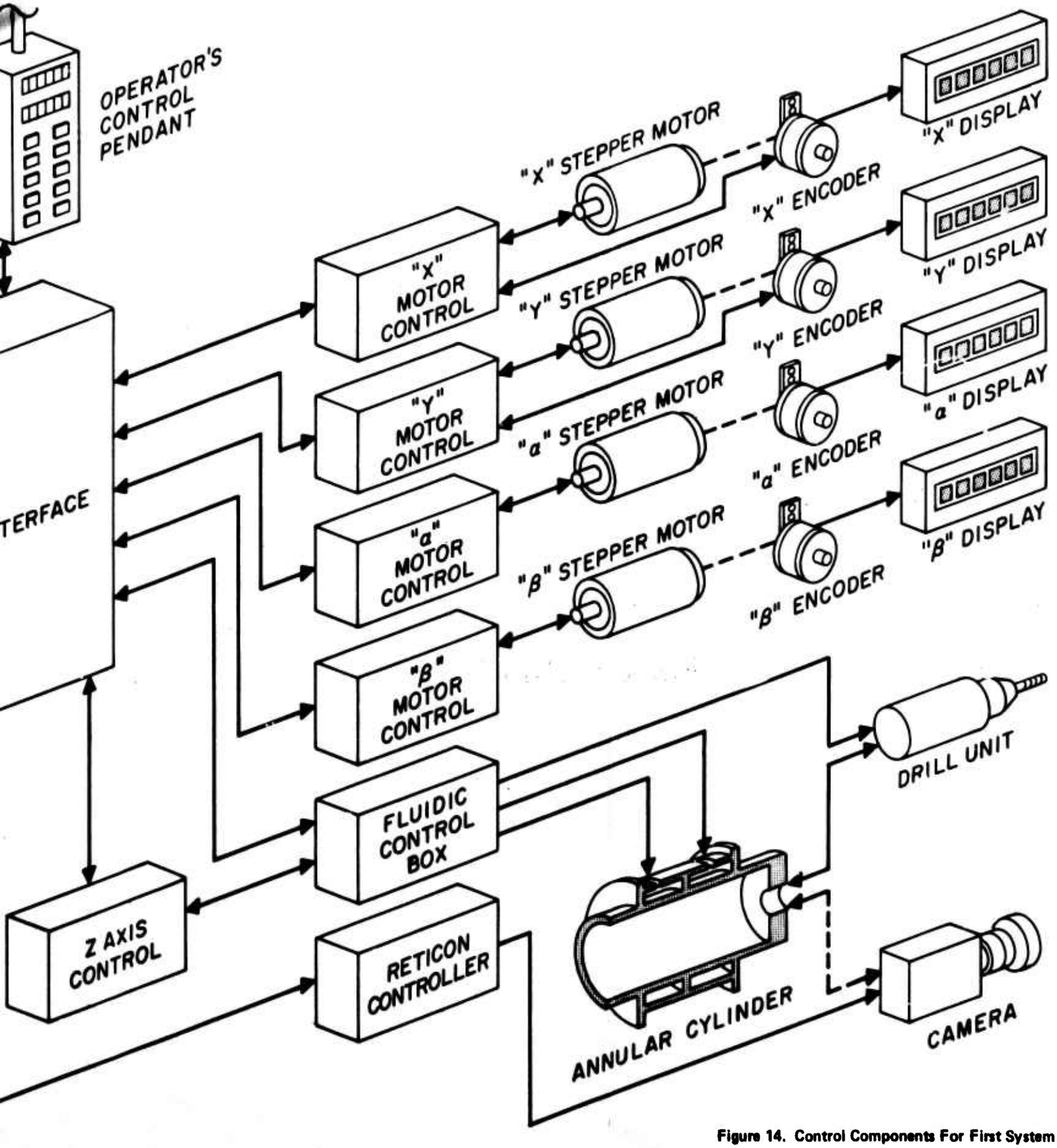


Figure 14. Control Components For First System

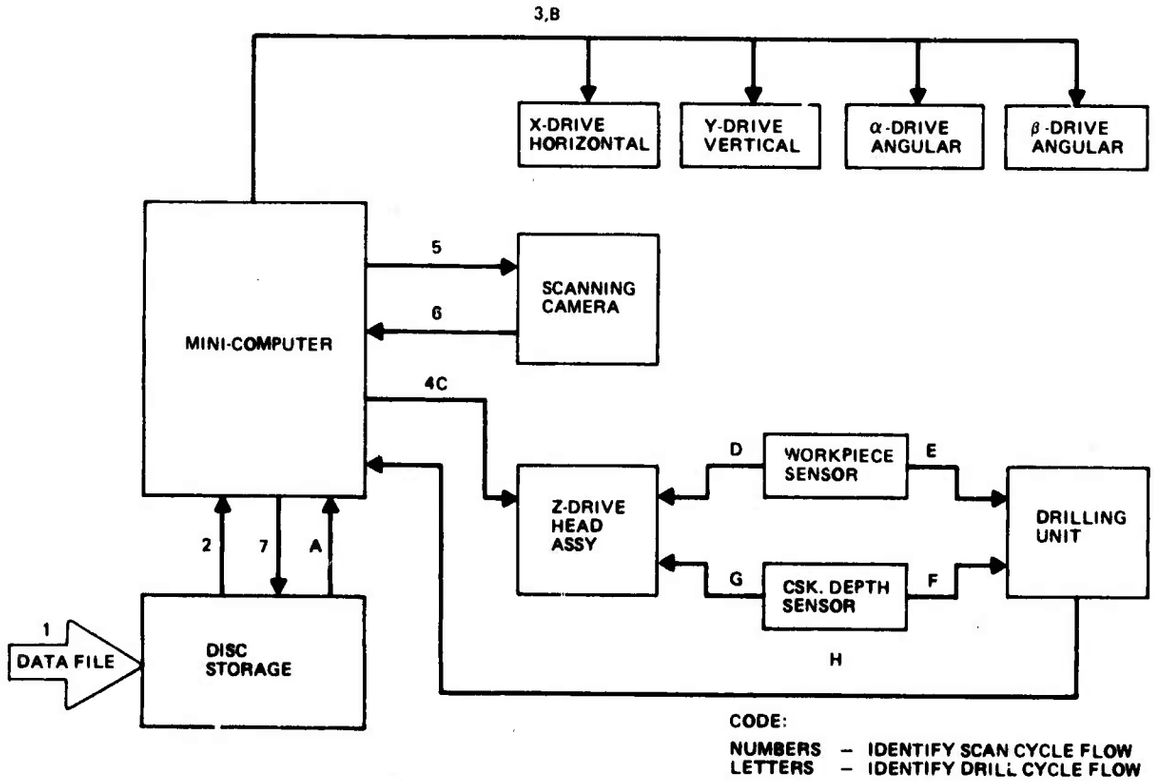


Figure 15. Flow Diagram for Five-Axis Automatic Scanning and Drilling System

3. The computer issues scan camera position signals to X, Y, α, and β stepper motor drives after having compensated for the edge distance

4. The computer issues a signal to the head assembly air cylinder for rapid advance to the pre-programmed Z-axis position, or until the focal length limit stop is contacted

5. The computer sends a signal to activate the scan camera, causing the structure edge to be illuminated. Light reflected from the structure into the camera determines structure edge position relative to nominal computed position from the master coordinate map and programmed edge distance.

6. The camera transmits a signal to the computer identifying actual structure position

7. The computer performs the necessary mathematical calculations to correct the nominal hole position to a position which will be a function of the actual structure position. This data is then stored on the disc for use during the drilling phase. It should be noted that scanning for the edge position of structure or workpieces does not necessarily have to be done for every hole but rather on a sampling basis for a row of holes, with all holes in a given row receiving a proportionate correction factor.

Steps 2 through 7 are repeated until all of the preprogrammed scan points have been obtained and all holes corrected.

The sequence of events for the drill cycle flow is as follows:

1. At the start of the drilling cycle a drill unit is inserted in the head assembly and the corrected hole position data is sent from the disc to the computer

2. The computer issues a signal to the X, Y, α , and β stepper motor drives

3. The computer issues a signal to the head assembly air cylinder to rapidly advance to the workpiece on the Z axis

4. The workpiece sensor detects contact between the drill unit nose piece and workpiece and sends a pneumatic signal to stop Z axis motion and hydraulically lock the head assembly air cylinder position

5. The workpiece sensor also sends a pneumatic signal to start advance of the drill into the workpiece

6. The countersink depth sensor detects the preset drill stroke for the purpose of producing a precise countersink depth in the hole. The sensor sends a pneumatic signal to the drill unit, stopping the drill feed and causing it to retract

7. The countersink depth sensor sends a pneumatic signal to the head assembly causing the air cylinder to hydraulically unlock and retract

8. Retraction of both drill unit and annular cylinder off workpiece causes a signal to be sent to the computer identifying completion of hole drilling cycle.

Steps 2 through 8 are repeated until all holes are drilled.

C. CONTROL SYSTEM COMPONENTS

The principal control system components are:

Component	Manufacturer	Part Number
• Computer	Digital Equipment Corporation (DEC)	PDP-8/E
Digital I/O	DEC Input Output	M1703 M1705
Positive I/O Bus	DEC	KA8-A
Power Fail & Restart	DEC	KP8-E
• Disc Storage	DEC	RK8-EA
• Scan Camera	Reticon Corporation	LC 600-512
• Camera Controller	Reticon Corporation	RS 605

Component	Manufacturer	Part Number
• Electronic Interface	Grumman-designed Using DEC Module	
• Fluidic Controller (Z-Axis Control)	Grumman-designed Using Corning Fluidic Gates	
• X & Y Motor Drives	Sigma Instruments Inc.	29B-04-024
• Alpha & Beta Motor Drives	Computer Equipment Corporation	VDR-CC4-1008
• Serial Data Interface	Grumman	
• Operator's Control Pendant	Grumman Design	
• Self-Scan Display	Burroughs	SSD0132-0060
• Serial Data Link	Grumman Design	One for each drill head and the computer
• Real-Time Clock	DEC	DK8-EC

1. Computer

The Digital Equipment Corporation's PDP-8/E Mini-Computer directs data flow to and from the drill fixtures, sequences the proper flow of events, and performs certain housekeeping and system checks. The Mini-Computer also performs all mathematical calculations required to correct the master coordinate map for minor deviations in placement of the understructure. The computer is equipped with a power fail option which enables the program to automatically restart after a power failure without losing data.

2. Disc Storage

The disc used for mass storage of coordinates has a capacity for 1.6 million 12-bit words which gives a capability of storing 200,000 coordinates. The use of a disc for coordinate storage satisfies the need to have a fast random-access storage device while keeping cost within manageable bounds. Core storage costs are in the range of $0.49 per word, whereas the cost for disc storage is only $0.0048 per word.

Since most aircraft structures are composed of left- and right-hand parts, only the master coordinates maps for one (the left hand) need be stored on the disc. When the modular drilling unit is moved to a right-hand fixture, the control system will perform the mirror-image function necessary to obtain the true coordinates. It is possible, due to the modularity concept, to move the drill carriages among as many fixtures as desired, subject only to the storage capacity of the disk described above. The file directory and disc storage allocation are handled by the DEC OS/8 software package. The format of the drilling data files is shown in Fig. 34 and 35.

During the scan mode, coordinates are read into the computer core memory in blocks of 24 coordinates. When the computer buffer is full, the corrected coordinates are transferred back to the disc and stored in a separate area known as The Corrected Coordinate Area. Transfer times for a block of 24 coordinates are in the order of 30 msec (nominal) and 100 msec (worst case).

The data stored on the disc as records are of three types:

- Coordinate - contains the coordinate information for the five-axis fixture and some auxiliary information
- Auxiliary - contains the bulk of the auxiliary information required
- Leader - contains the tables necessary to initialize the system.

Each disc block (256 cpu words) contains 24 of these records, one dummy record, and a block header. The records will be transmitted to the run-time system with high-level 'READ' and 'WRITE' constructs.

3. Scan Camera and Controller

A master coordinate is corrected based on the data received from a digital scanning camera looking at the edge of the member to be drilled. Reticon Corporation's Model LC-600-G-512-1 camera (Fig. 16) contains, as its light converter, a linear array of 512 photodiodes. Each diode develops an electrical charge across an associated capacitor proportional to the intensity of the light and to the time that it is exposed to the light. The charge on each diode is sent sequentially to a charge amplifier which produces a short

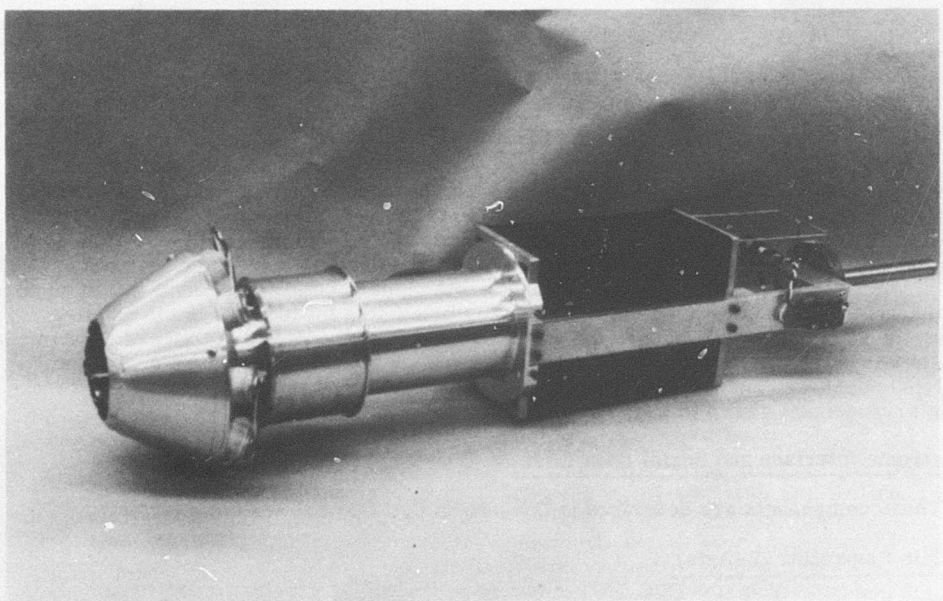


Figure 16. Digital Scanning Camera

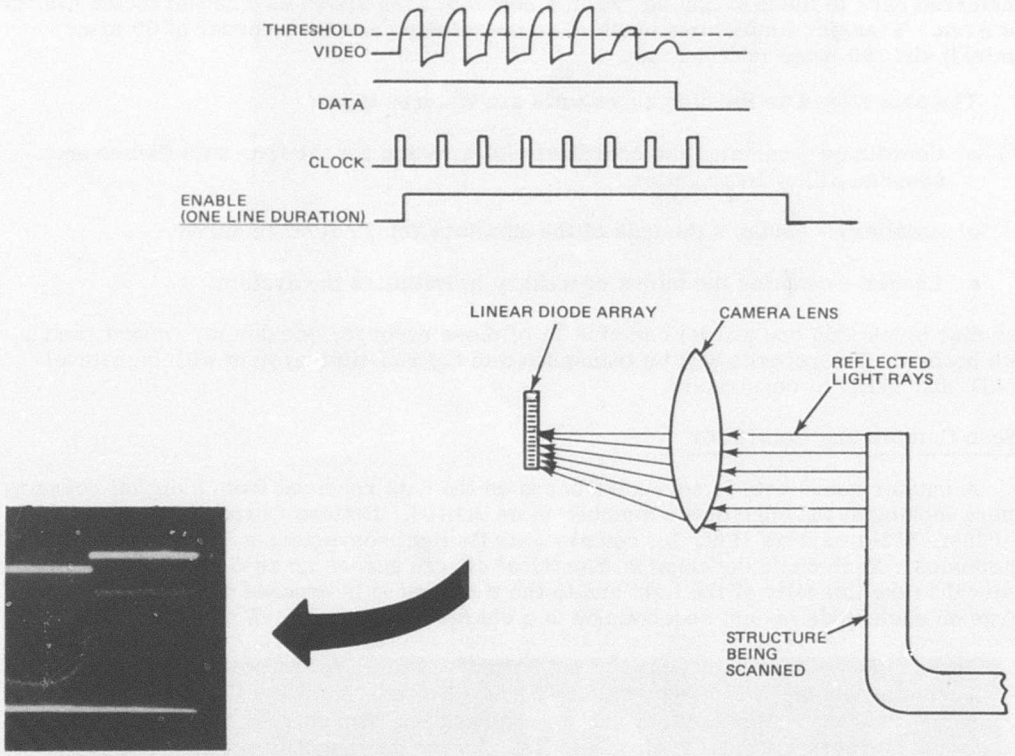


Figure 17. Digital Scanning Camera Operation

pulse whose height is proportional to the charge on the diode. The diode is reset to zero charge and the next diode, in turn, is interrogated in the same fashion. The entire array is scanned, producing a train of output pulses from the camera as illustrated in Fig. 17. Figure 18 shows the camera video output for several scans of an actual test stringer. Each pulse is compared to a threshold value and a remote camera controller counts the number of diodes which produces voltages either above or below this threshold. In the existing system, the number of diodes above the threshold is counted. The sensitivity of the camera can be increased by increasing the light intensity and/or slowing the scan rate. A scan rate of 100 scans/sec and a reflected light intensity of 2000 ft-candles derived from the lighting arrangement shown in Fig. 19 has proven to be adequate.

4. Electronic Interface and Serial Data Link

These components are described in Subsection C, "Control System Interfacing."

5. Fluidic Controller (Z-Axis)

The Z-axis is positioned by an annular cylinder under the control of a fluidic circuit shown in Fig. 12. On a typical drill/countersink operation the sequence is as follows. An electrical or manual pulse sends a pneumatic pulse to the annular cylinder control valve

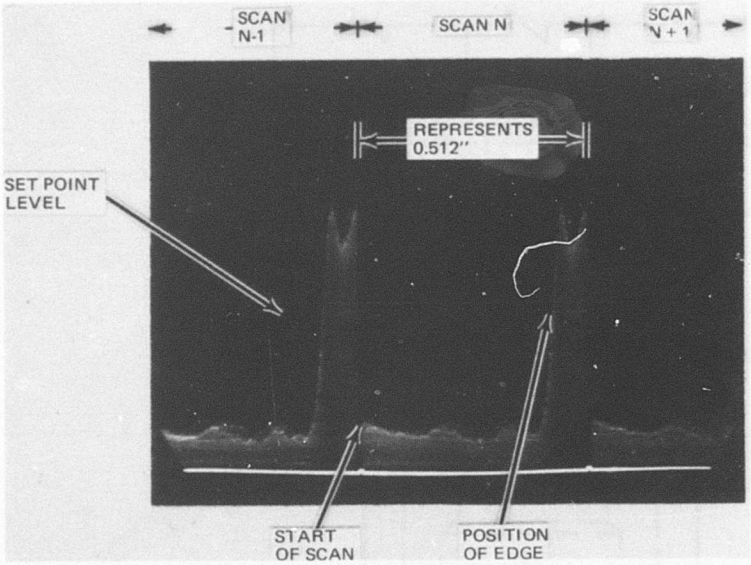


Figure 18. Video Output of Camera on Test Stringer

which, in turn, pressurizes the cylinder advancing the drill unit forward. As the nosepiece contacts the material, a fluidic bleed port is closed off. The buildup in pressure thus caused is detected by a fluidic back pressure switch which, in combination with other fluidic devices, sends a pressure signal to start the drill motor and lock up the hydrocheck. When the countersink reaches the correct depth another fluidic bleed port is blocked, creating a back pressure signal which is sensed by a fluidic device. This fluidic signal is used to reset the drum cylinder control valve, enabling air pressure to retract the cylinder. The same signal retracts the drill motor spindle. As the drill motor retracts, a pressure signal is sent to an electric switch which signals the computer to move the head to the next location.

The Corning fluidic components used are back-pressure switches, flip-flop, AND/NAND, timers and OR/NOR gates. Two Bellows signalizer fluidic control valves are used to send high-pressure air to the annular cylinder, drive start signal, and the Bellows hydrocheck. These components, in combination with filters, regulators, pressure switches, and solenoid shut-off valves, work well as a circuit and are used in drilling production wings.

A digital-to-analog (D/A) converter exists in the interface unit which converts the digital value from the computer to an analog voltage proportional to the binary weight, as shown in Fig. 20. The analog voltage is applied to a circuit which produces a high logic level on one line if the cylinder must be extended and a high logic level on the other line if the cylinder must be retracted. These lines are applied to the fluidic circuit to actuate the pneumatic signal to the cylinder and the hydrocheck. The feedback signal is provided by a linear potentiometer with a stroke of 12 in. When the voltage on the potentiometer wiper is equal in magnitude to the output of the D/A converter, Z motion ceases. The computer acknowledges that the cylinder is in the correct Z position and activates the camera control system.

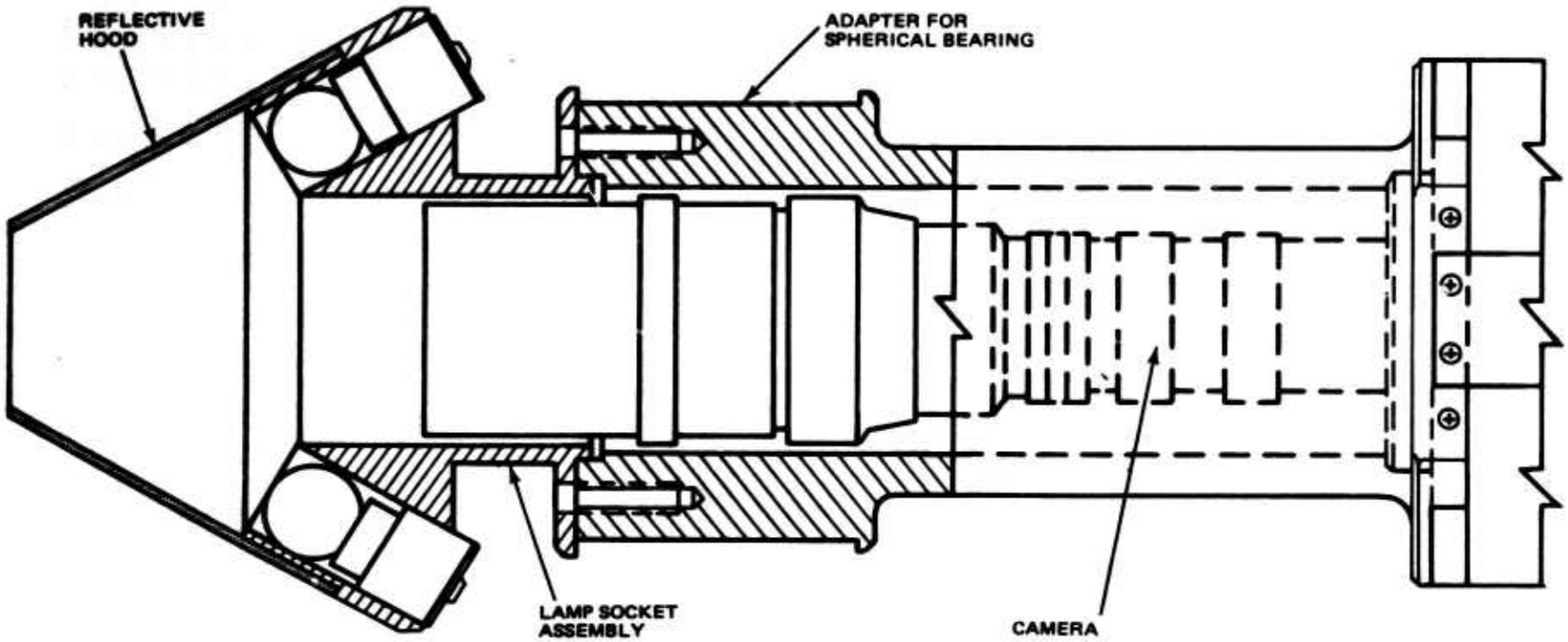


Figure 19. Lamp and Reflecting Hood Assembly

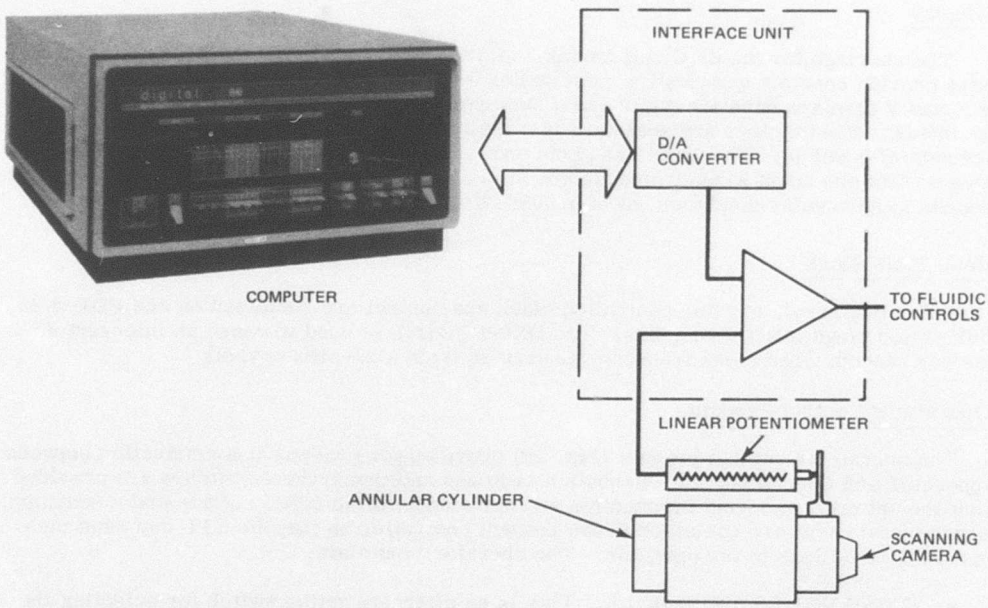


Figure 20. Z-Axis Control System

There is an adjustable dead-zone region in which the cylinder does not move; this is intended to prevent cylinder oscillation. It has been found that the optimum setting for the dead-zone results in a Z-axis position uncertainty of only 0.03 in., well within scan camera tolerance limitations.

6. X, Y, Alpha, and Beta Drive Systems

The computer processes the coordinate information and loads the drive system with the necessary information for driving the stepper motors to position the drill or scan camera. The prime movers for X, Y, α , and β are stepper motors which take 200 steps per shaft revolution. For the X and Y axes, the motor output shafts are geared down to produce a linear motion of 0.001 in. for each step of the motor. In the α-axis, each motor step produces an angular change of 0.00524 degree on the camera or drill unit, while for β each step results in an angular displacement of 0.00544 degrees.

The motor control cards contain counters which are loaded, from the computer, with the number of steps the motors are to take. The computer also sets or resets a "flip-flop" depending upon the direction of rotation desired. The X and Y axes each contain an encoder whose outputs are fed back and used to count-down the counters. Deceleration of the mass is accomplished by the control system logic which causes the motors to begin slowing down when the counters count down to the point where there are only 2 in. of travel remaining. Stopping occurs when the counter is empty. The point at which the motors begin to decelerate is controlled by the computer (Fig. 3). The rates of deceleration and acceleration, however, are independently set by the hardware to an optimum point. Encoder feedback minimizes the adverse effects of the backlash inherent in the drive system by forcing the stepper motors to drive until the drill unit or camera is properly positioned.

7. Display

The carriage for the drill unit contains digital display units for the X, Y, α, and β axes to provide constant quantitative information as to the position of the drill or camera. The X and Y displays have six digits and a sign capable of displaying dimensions up to ±999.999 in. The displays are scaled so that the least significant digit corresponds to a movement of 0.001 in. The alpha- and beta-axis displays have four digits and a sign scaled so that one count is equivalent to one step of the stepper motor. For alpha, this corresponds to an angular displacement of 0.00524 degree and for beta, 0.00544 degree.

8. Real-Time Clock

A fixed-interval, crystal-controlled clock and control are contained on one PDP-8/E module which plugs into the omnibus. The DK8-EC clock is used to cause an interrupt 50 times per second. The clock frequency is derived from a 20-MHz crystal.

9. Operator's Control Pendant

The operator's control pendant (Fig. 21) provides for two-way communication between the operator and the computer. Pushbutton switches and thumbwheel switches are provided so that the operator can send information and commands to the CPU. Lights and a scanning message display unit are contained in the pendant controller so that the CPU can send messages and instructions to the operator. The operator inputs are:

- FINISH HOLE/CLECO HOLE. This is an alternate action switch for selecting the type of hole to be drilled. Cleco fastener holes are normally selected first because the temporary Cleco fasteners hold the part in place during the major drilling portion of the cycle

- SCAN/DRILL. This is an alternate action switch for selecting the scan or drill mode. All holes must be scanned prior to being drilled

- HOLES/OPERATION. This is an alternate action switch for selecting the holes which are to be scanned or drilled. When the switch is set to HOLES, the left five-digit, thumbwheel bank of switches must be used to enter the starting hole number; the right thumbwheel bank must be used to enter the last hole number. When the switch is set to OPERATION, the left thumbwheel switch bank must be used to designate the starting operation number and the right thumbwheel switch must be used to designate the last operation number

- SKIP HOLE. This is an alternate action switch for bypassing drilling of a hole. This switch must be set before the drilling command is issued by the computer. The automated drill head will move to each hole position but will not drill the holes as long as this switch is set

- SLASH DELETE. This is an alternate action switch that will delete data in the parts program if such data occur after the "Slash" command

- SINGLE CYCLE. This is a momentary action switch that allows only one hole to be scanned or drilled whenever the "Continue" switch is depressed. After the hole is scanned or drilled, the system is put into a CYCLE STOP mode

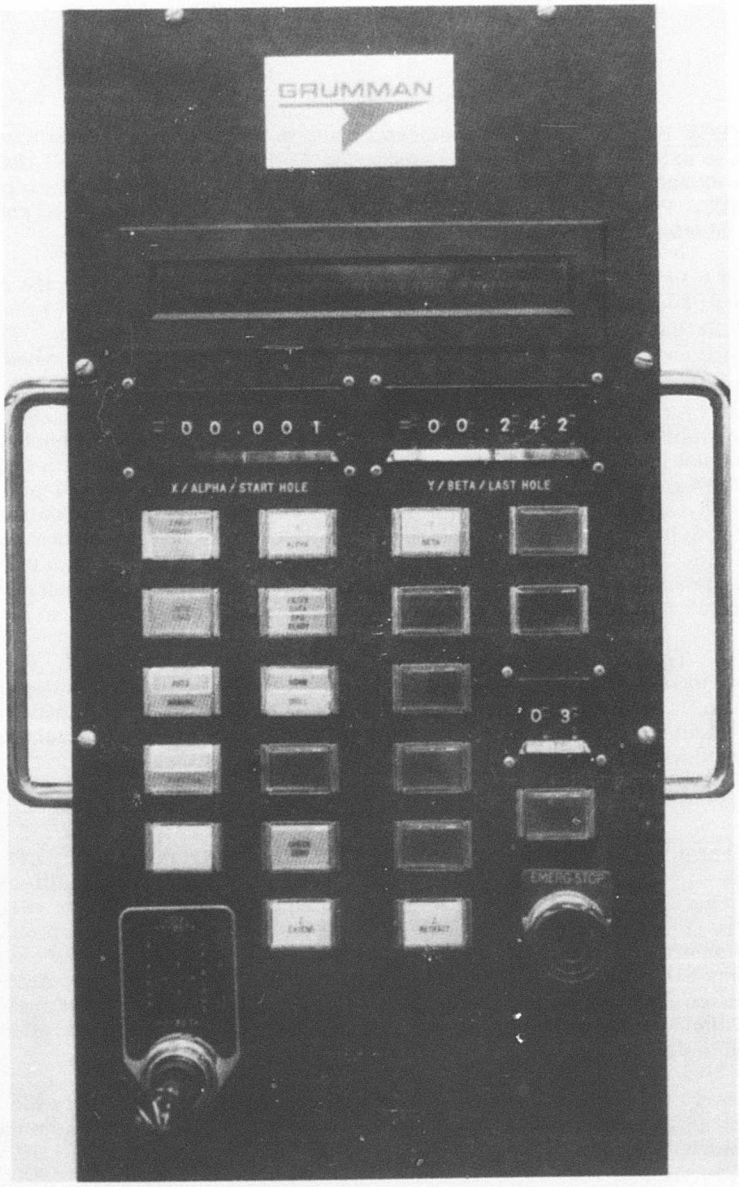


Figure 21. Operator's Control Pendant

- CHECK ZERO. This is a momentary action switch that will command the "At Zero" pin to extend while it is depressed. The CHECK ZERO lamp will illuminate if the pin extends fully, thereby indicating that the machine is at the zero position. The CHECK ZERO lamp is illuminated for both the computer-actuated and manual pushbutton commands

- DATA LOAD. This is a momentary action switch which signals the computer that the FINISH HOLE/CLECO HOLE, AUTO/MANUAL, SCAN/DRILL, and HOLES/OPERATION switches have been pressed for the automatic cycle. The START HOLE and LAST HOLE thumbwheel switches are preset as described previously

- DISPLAY REQUEST. This is a momentary action switch which indicates that the two-digit thumbwheel above the switch has been preset. The thumbwheel data will instruct the computer to have a specific message or piece of data displayed on the Burroughs self-scan display. The Burroughs self-scan panel display is used to display operator-requested information and computer-initiated messages. The display is a 32-character-position, gas-discharge matrix that is compatible with the ASC II code and provides a repertoire of 64 characters in a 5 x 7 -dot matrix. The Burroughs display contains a memory and utilizes right-to-left character entry. The display can be viewed at distances up to 12 ft.

- JOG. This is a momentary action switch that can control the X, Y, Alpha, and Beta axes. The X/ALPHA and Y/BETA alternate action pushbuttons must be preset to the desired axis to be moved. The JOG switch will command both axes selected if it is moved on a 45-degree angle, as well as individual axes if it is moved horizontally or vertically.

D. CONTROL SYSTEM INTERFACING

The first system entailed the transfer of information from the computer in the drilling unit interface in parallel format, that is, one wire per signal. In the multi-user interface system, all data from the computer to the individual drilling units is sent serially over a pair of wires. In addition, this pair of wires can be "daisy chained" from one drilling assembly to another as depicted in Fig. 22. The advantage of sending the data serially is that much less cabling is required and transmission distance can be economically increased. In an application such as the automated assembly drilling fixture, the fixtures can be removed from the computer and interface (up to 600 feet), resulting in a large expenditure for cable and cable drivers.

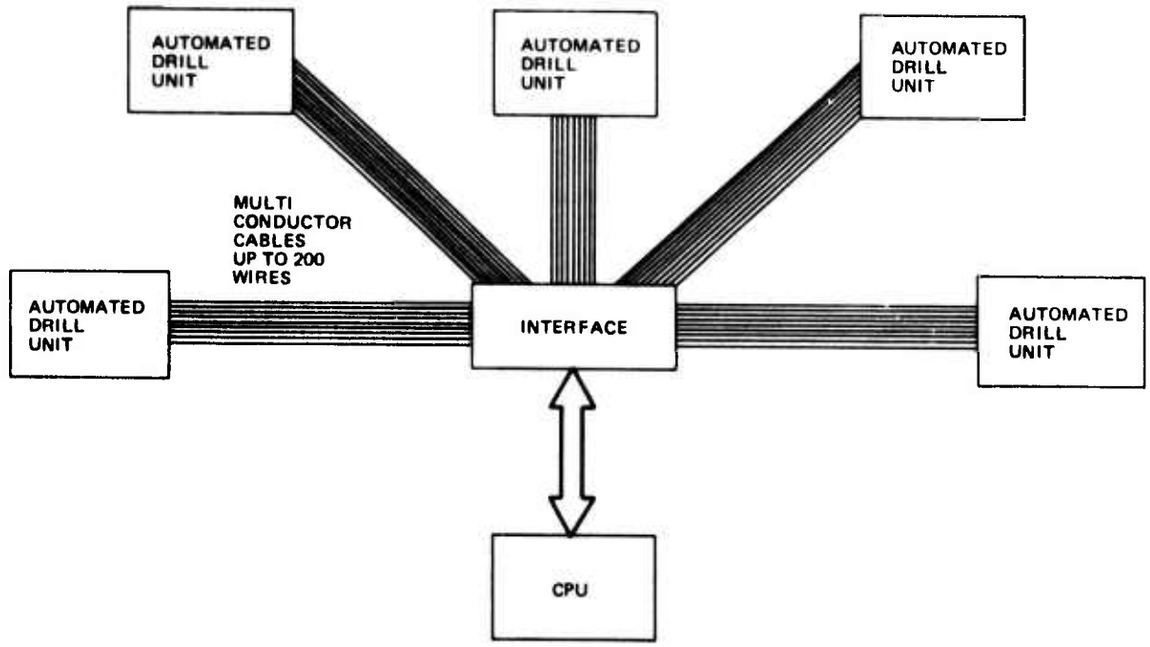
The heart of the interface is the Grumman serial data link known as the Standard Interface Unit (SIU). There is one SIU at the computer and one at each automated drilling machine. Block diagrams of the system are shown in Fig. 23.

All SIU's are identical in construction and operation. Each remote SIU has the following functions:

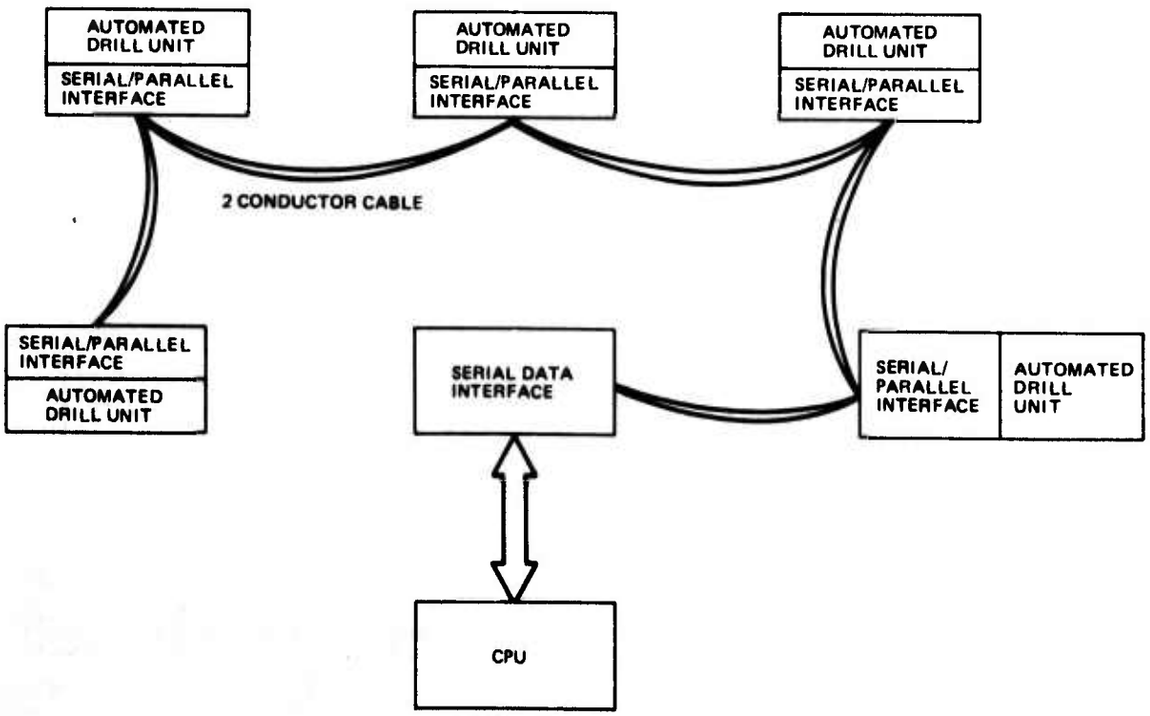
- Unique programmable "address designator" which defines its name to the System

- Receives or transmits data on command to the master SIU located at the computer

- Monitors its own transmissions as well as those from the master SIU for correct data word lengths and parity



a. PARALLEL



b. SERIAL

Figure 22. Data Transfer

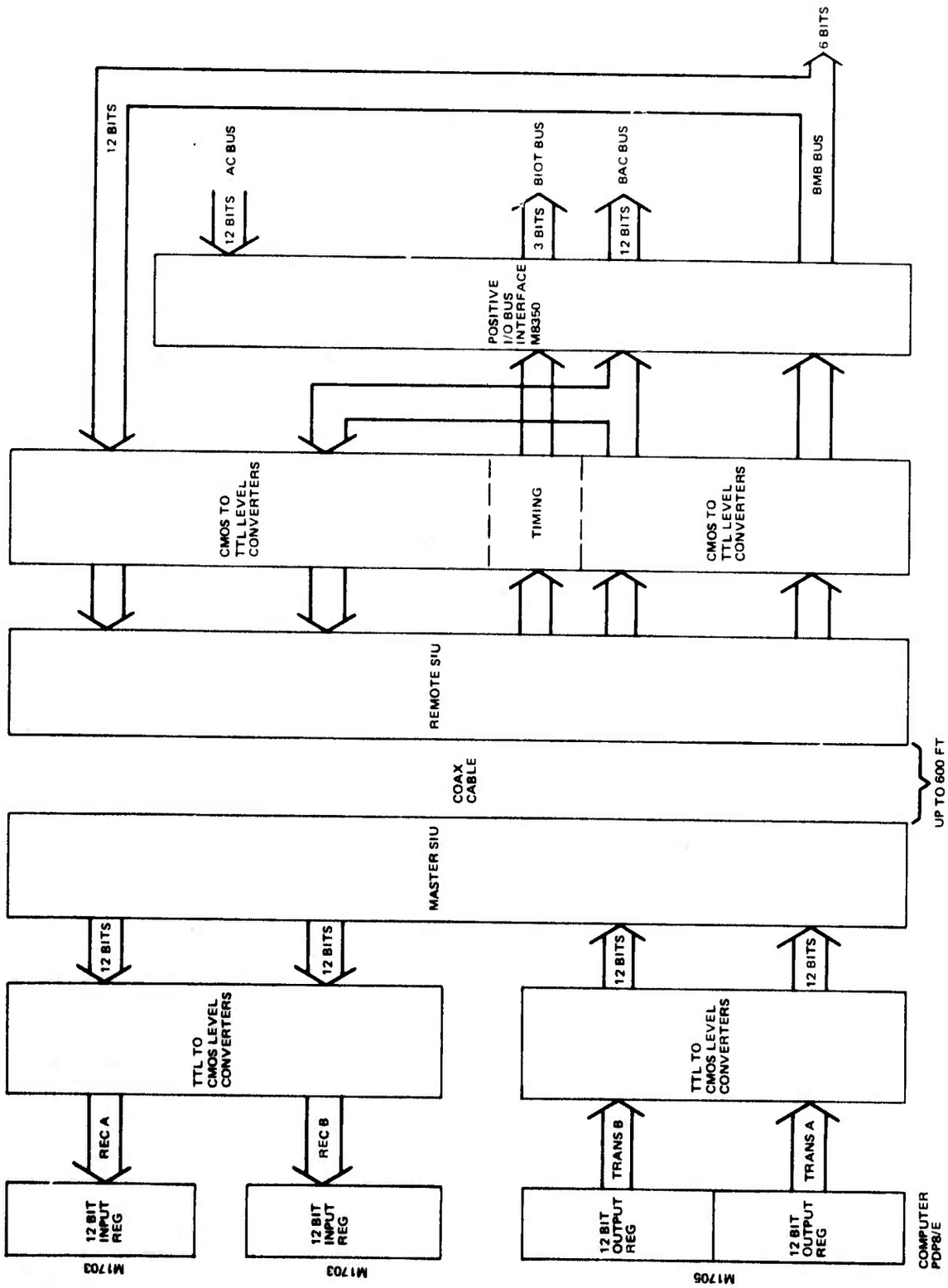


Figure 23. Block Diagram of Standard Interface Unit

- Upon recognition of an improper data transmission, prevents the data from being transferred to its controlling device, i. e., the computer for the Master SIU and the Machine Control Interface for each Remote SIU.

The SIU's transmit a train of 32 bits at a rate of 1,000,000 bits/sec. The transmission utilizes a self-clocking Manchester Code.

The computer interface to the Master SIU consists of three standard Digital Equipment Corporation (DEC) modules which plug directly into the computer omnibus and two level conversion modules located in an interface rack with the Master SIU directly below the computer. The interface between the computer and the Master SIU consists of a 24-bit input register and a 24-bit output register, as shown in Fig. 23. Data are transferred in two 12-bit bytes. The three standard DEC modules (two M1703s for input and one M1705 for output) contain device selection logic to address an external device, an operation decoder to determine the type of interface operation, storage registers to buffer the data, interrupt control logic, and bus driver/receivers to allow operation on the computer omnibus. Connections to and from the interface are made via standard cables that plug into the module boards.

A transfer of data to the automated drill fixture electronics is accomplished by loading the Master SIU with 12-data bits and 12 address and control bits. Figure 24 shows the correlation between the computer bit assignments and the Master SIU bits. Three bits are used for machine head address, six bits for sub-unit address, and three bits for the control functions. The 24 bits thus loaded into the Master SIU are shifted out serially to all of the remote SIUs. Only the remote SIU that recognizes its three-bit address code will permit the rest of the 24 bits to enter.

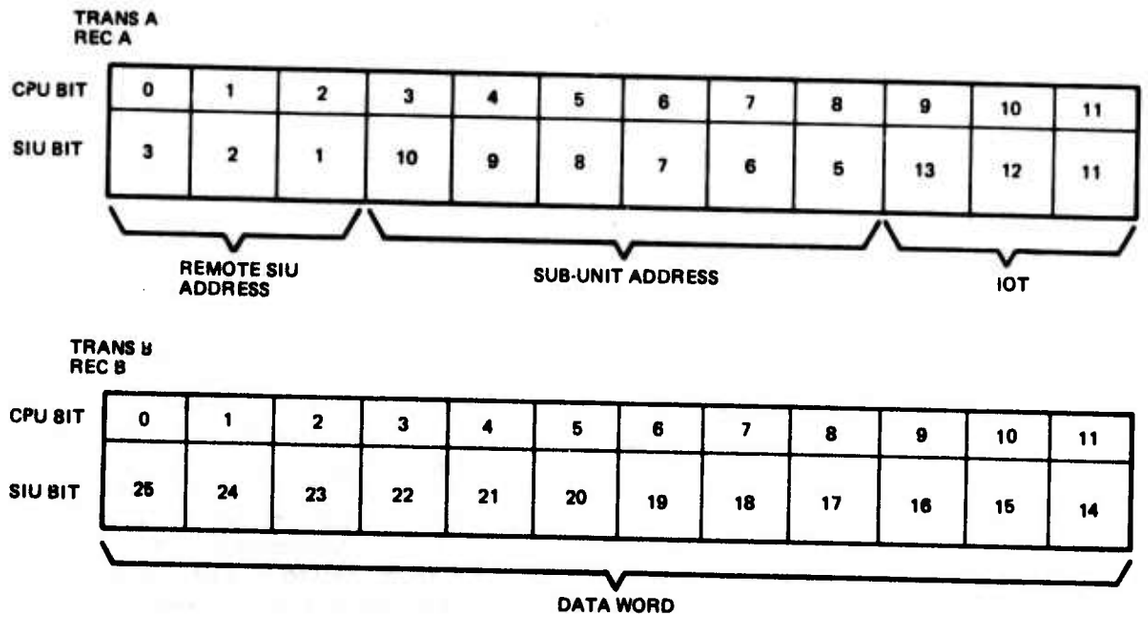


Figure 24. Correlation Between Computer-Bit Assignments and Master SIU Bits

The machine tool interface to the remote SIU is shown in Fig. 23. The 24 bits received by the remote SIU are converted from CMOS logic levels (+10V DC) to TTL (transistor-transistor logic +5 VDC). The control signals of the remote SIU are used to generate timing for the Positive I/O module (DEC KA8-E). The positive I/O module receives the two 12-bit words, buffers them, and makes them available to the machine control interface. The positive I/O module also decodes the three control function bits and generates one of three possible IOP pulses (BIOP1, BIOP2, or BIOP4). The six sub-unit address bits are decoded by each of the multiplexers (DEC M734 Modules), and the device selected will enable the BIOP pulse to be transferred to the register to be loaded. The BIOP enables the 12-bit data word to be loaded and also effects the transfer of the register output to the AC/BUS through the multiplexer. This enables the SIU to transmit the loaded data back to the Master SIU where it is checked by the computer for accuracy. When only a "read" is required (such as reading thumbwheels), the loading sequence by the BIOPs is disabled; thus only reading of the data held by the register is performed. This type of interface operation enables all data transmissions to be verified for accuracy, since the 12-bit address is also fed back to the remote SIU from the output of the positive I/O module. Tables 1 and 2 show how each remote register is used.

The multi-user system utilizes absolute counters for the X, Y, Alpha, and Beta axes to prevent the possibility of the machine being moved to a position unknown by the computer. The absolute counters will always be enabled and will always indicate the true machine position. Because the previous single-user system utilized incremental counters, the burden of keeping track of the true machine position was left up to the computer. Reading the overshoot or undershoot of a move in the single-user system was accomplished after a software time delay to allow the machine to stabilize. In the present multi-user system, the hardware delays the "Axis Done" signals from being asserted until a sufficient time has elapsed since the last axis completed its move. This hardware delay allows the computer to operate more efficiently by not having to delay reads of the different absolute counter registers.

The KA8-E positive I/O module is used for system flexibility. With the module plugged into the Remote Machine Tool Interface rack, the machine is operated in the multi-user mode with data being transmitted serially from the computer to the machine by way of the SIU data link.

E. ADAPTABILITY TO MINOR POSITION VARIATIONS

The control system corrects the basic coordinates for minor position variations in placement of the components to be drilled. This is required since, due to the build-up of tolerances in the subassembly fabrication, stringers, beams, ribs and clips will generally be placed with an uncertainty in position of perhaps ± 1/8 to ± 3/16 in. This uncertainty in positions is in the direction that does not allow holes to be placed automatically under N/C control, as shown in Fig. 25. If a method is not provided for adjusting the hole to the actual built-up position of the understructure, the required hole edge-distance will not be maintained and the drill may put a hole closer to the edge than the tolerance will allow (a typical tolerance being ± 1/32 in.). To prevent this, the manual method of hole preparation involves a time-consuming procedure of first putting the drill template on the understructure to check where the drill template must be moved to get proper edge-distances for variations in the substructure's position. The production floor mechanic accomplishes this through a series of appropriate manual adjustments to the template position.

Table 1. Listing of Remote Registers

REGISTER ADDRESS	MNEMONIC	ϕ	1	2	3	4	5	6	7	8	9	10	11
301	XMSILR	MSB											LSB
302	XLSILR	MSB											LSB
304	XDSILR	MSB											LSB
311	XM3IR	MSB											LSB
312	XLSIR	MSB											LSB
314	XDSIR	MSB											LSB
321	YMSILR	MSB											LSB
322	YLSILR	MSB											LSB
324	YDSILR	MSB											LSB
331	YMSIR	MSB											LSB
332	YLSIR	MSB											LSB
334	YDSIR	MSB											LSB
341	ASCILR	MSB											LSB
342	ADCILR					MSB							LSB
344	BSCILR	MSB											LSB
351	ASCIR	MSB											LSB
352	ADCIR					MSB							LSB
354	BSCIR	MSB											LSB
361	BDCILR					MSB							LSB
362	XMSALR	MSB											LSB
364	XLSALR	MSB											LSB
371	BDCIR					MSB							LSB
372	XMSAR	MSB											LSB
374	XLSAR	MSB											LSB
401	YMSALR	MSB											LSB
402	YMSALR	MSB											LSB
404	AABSLR	MSB											LSB
411	YMSAR	MSB											LSB
412	YLSAR	MSB											LSB
414	AABSR	MSB											LSB
421	BABSLR	MSB											LSB

Table 1. Listing of Remote Registers (Cont)

REGISTER ADDRESS	MNEMONIC	ϕ	1	2	3	4	5	6	7	8	9	10	11
422	DCBLR	X + = 1 - = 0	Y	A	B								
424	CBLR	X	Y	A	B	Z	DRILL	SCAN	EXTEND AT ZERO CYL.	ROTATE CAMERA			
431	BABSR	MSB											LSB
432	DCBR	X + = 1 - = 0	Y	A	B								
434	CBR	X	Y	A	B	Z	DRILL	SCAN	EXTEND AT ZERO	ROTATE CAMERA			
441	ZDACLR	SET TO 1 TO CLEAR OUT BITS 1 - 11		MSB									LSB
442	HSRCR	LOGIC POWER LOW	LIMIT SW OVER-TRAVEL	SCAN LAMP OUT	BROKEN TOOL		X, Y A & B AXIS AT POSITION	DRILLING COMPLETE	SCAN COMPLETE	LOOK AT CONTROL PANEL	EMERG. STOP	Z AXIS AT POSITION	
451	ZDACR			MSB									LSB
452	HSRR	LOGIC POWER LOW	LIMIT SW OVER-TRAVEL	SCAN LAMP OUT	BROKEN TOOL		X, Y, A & B AXIS AT POSITION	DRILLING COMPLETE	SCAN COMPLETE	LOOK AT CONTROL PANEL	EMERG. STOP	Z AXIS AT POSITION	
471	HSRRI	AT ZERO L.S.	X MOVING	Y MOVING	A MOVING	B MOVING	Z MOVING	+ X L.S.	- X L.S.	+ Y L.S.	- Y L.S.	ANGLE L.S.	NOSE PIECE L.S.
472	HSRR2	CAMERA CW L.S.	CAMERA CCW L.S.	←	GANTRY NUMBER		→	←		FIXTURE NUMBER $2^6 = 64$			→
474	RTNR (BCD)	MSB											LSB

Table 1. Listing of Remote Registers (Cont)

REGISTER ADDRESS	MNEMONIC	φ	1	2	3	4	5	6	7	8	9	10	11
511	MDIAR			+	-	← 9 →				← 9 →			
512	MDIBR	← 9 →				← 9 →				← 9 →			
514	MDICR			+	-	← 9 →				← 9 →			
531	MDIDR	← 9 →				← 9 →				← 9 →			
532	CPSR2	MACH PWR ON	AUTO "1" MANUAL	SCAN "1" DRILL	FINISHED "1" CLECO	X "1" ALPHA	Y "1" BETA	SKIP HOLE		TEST "1" NORMAL	HOLES "1" OPERATION	SLASH DELETE	
534	CPSR3	ZERO CYLINDER P.B.	Z EXTEND P.B.	Z RETRACT P.B.	JOG ↑	JOG ↓	JOG ←	JOG →					
541	CPSCR1			DATA LOAD	CYCLE START	CYCLE STOP	CONTINUE	RETURN TO ZERO		SINGLE CYCLE	DISPLAY REQUEST		
542	SSDLR	← DATA →						DATA PRESENT 1μS MIN LOW	CLEAR 66μ SEC LOW	BLANK DISABLE "1"	BACK SPACE 1μS MIN LOW		
544	LHTLR	CPU READY	ENTER DATA	CYCLE START	CYCLE STOP	RETURN TO ZERO							
551	CPSR1			DATA LOAD	CYCLE START	CYCLE STOP	CONTINUE	RETURN TO ZERO		SINGLE CYCLE	DISPLAY REQUEST		
552	SSDR	← DATA →						DATA PRESENT	CLEAR	BLANK DISABLE	BACK SPACE		
554	LHTR	CPU READY	ENTER DATA	CYCLE START	CYCLE STOP	RETURN TO ZERO	SPARE W/LAMP	SPARE W/O LAMP					
571	ODRR					← 9 →				← 9 →			

Table 2. Operation of Remote Registers

REGISTER ADDRESS	CLEAR	LOAD	READ	MNEMONIC	OPERATION
301		X	X	XMSILR	X AXIS MOST SIG INCREM CNTR
302		X	X	XLSILR	X AXIS LEAST SIG INCREM CNTR
304		X	X	XDSILR	X AXIS DECEL SIG INCREM CNTR
311			X	XMSIR	X AXIS MOST SIG INCREM CNTR
312			X	XLSIR	X AXIS LEAST SIG INCREM CNTR
314			X	XDSIR	X AXIS DECEL INCREM CNTR
321		X	X	YMSILR	Y AXIS MOST SIG INCREM CNTR
322		X	X	YLSILR	Y AXIS LEAST SIG INCREM CNTR
324		X	X	YDSILR	Y AXIS DECEL SIG INCREM CNTR
331			X	YMSIR	Y AXIS MOST SIG INCREM CNTR
332			X	YLSIR	Y AXIS LEAST SIG INCREM CNTR
522					
524					
531			X	MDIDR	MANUAL DATA .999
532			X	CPSR2	CONTROL PANEL STATUS 2
534			X	CPSR3	CONTROL PANEL STATUS 3
541	X		X	CPSCR1	CONTROL PANEL STATUS 1
542		X	X	SSDLR	SELF SCAN DISPLAY
544		X	X	LHTLR	LOAD LIGHT GROUP I
551			X	CPSR1	CONTROL PANEL STATUS 1
552			X	SSDR	SELF SCAN DISPLAY
554			X	LHTR	LOAD LIGHT GROUP I
561					
562					
564					
571			X	ODRR	OPERATOR DISPLAY RQST
572					
574					

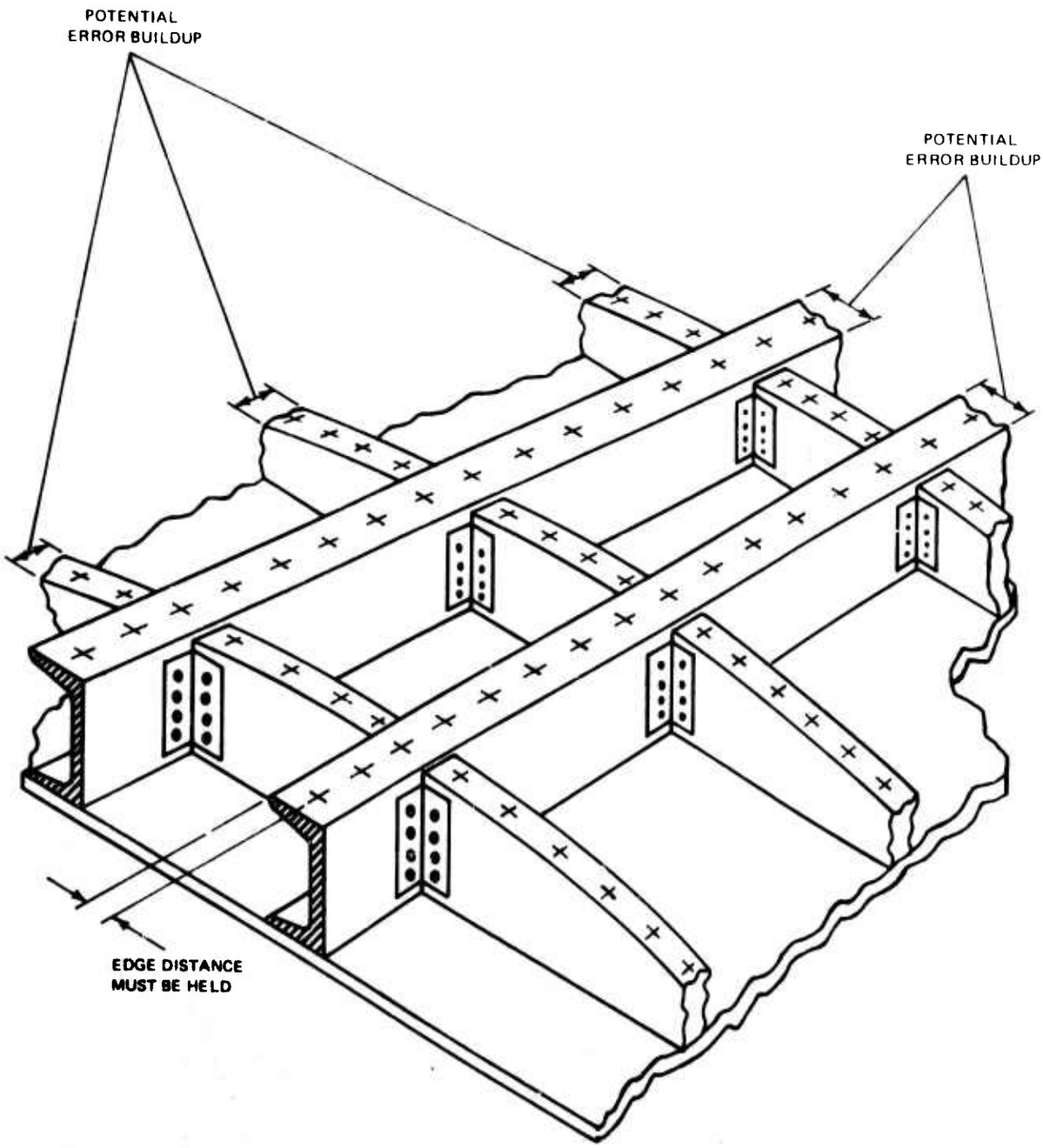


Figure 25. Typical Position Variation For Built-up Substructure

The automated drilling unit first scans the understructure with a digital scanning camera looking at the edge of the stringer, rib, etc. The data from the camera are then used to correct the nominal drill coordinate (known as the master coordinate map). These corrected coordinates are then used to automatically position a drill head for this part. This corrected coordinate cannot, however, be used for any other part since, in general, the variations in placement are random. The placement of the camera during a scan is shown in Fig. 26. Although the master coordinates are for nominal placement of the holes, the camera must be positioned at the edge of the stringer since it works on the principle of detecting reflected light. The offset of the camera, from the hole center to the edge of the structure, is handled by the computer. The computer also corrects the Z dimension for the alpha and beta angles, and corrects the X and Y dimensions for the camera focal length.

Once the camera is in position (Fig. 27), the actual edge is scanned and the information (δ) sent to the computer. If the structure is in the correct place, a reading of 256 will be received from the camera controller (or $\delta = 0$), indicating that half of the 512 photodiodes are in the light and half are in the dark. The camera-generated information will be used by the computer to calculate how much (ΔD) to move the hole coordinates to accommodate the actual placement of the understructure. The formulas used for the correction depend on the orientation of the stringer (α) and the direction of the edge. The camera diode array is placed vertically for stringer angles $-45^{o} \leq \alpha \leq 45^{o}$ and rotated to the horizontal position for angles $90^{o} \geq \alpha > 45$ or $-90^{o} \leq \alpha < -45^{o}$.

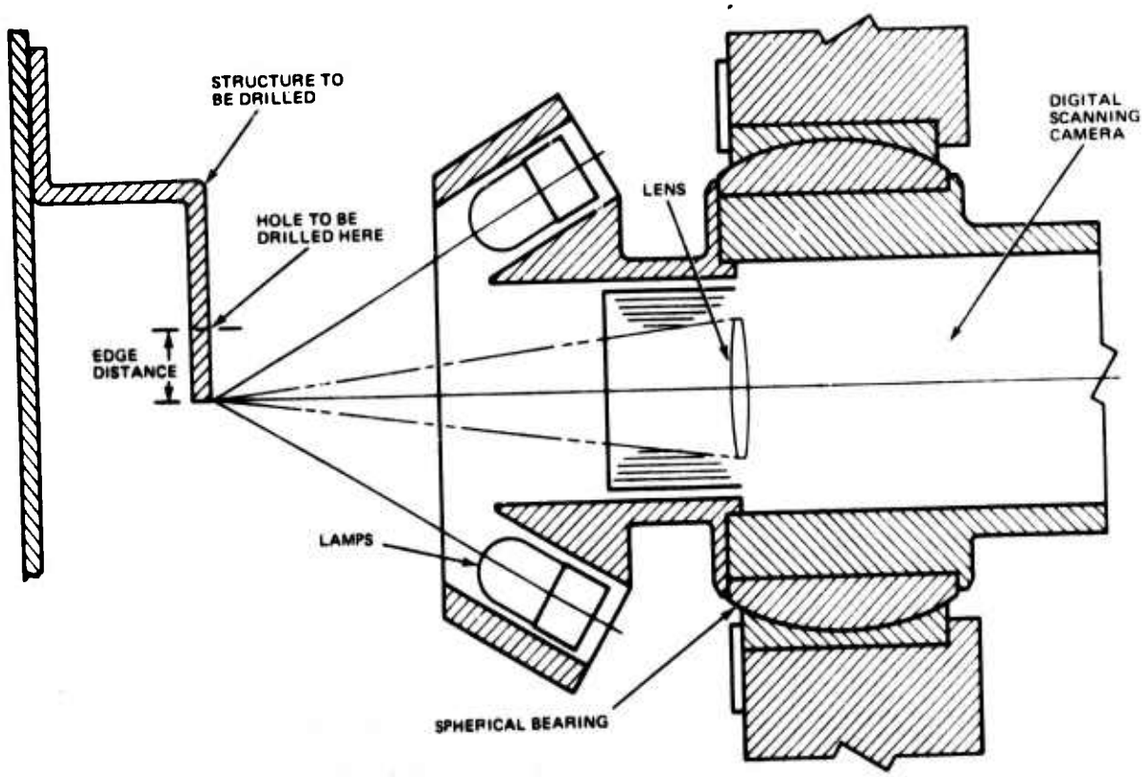


Figure 26. Camera Placement

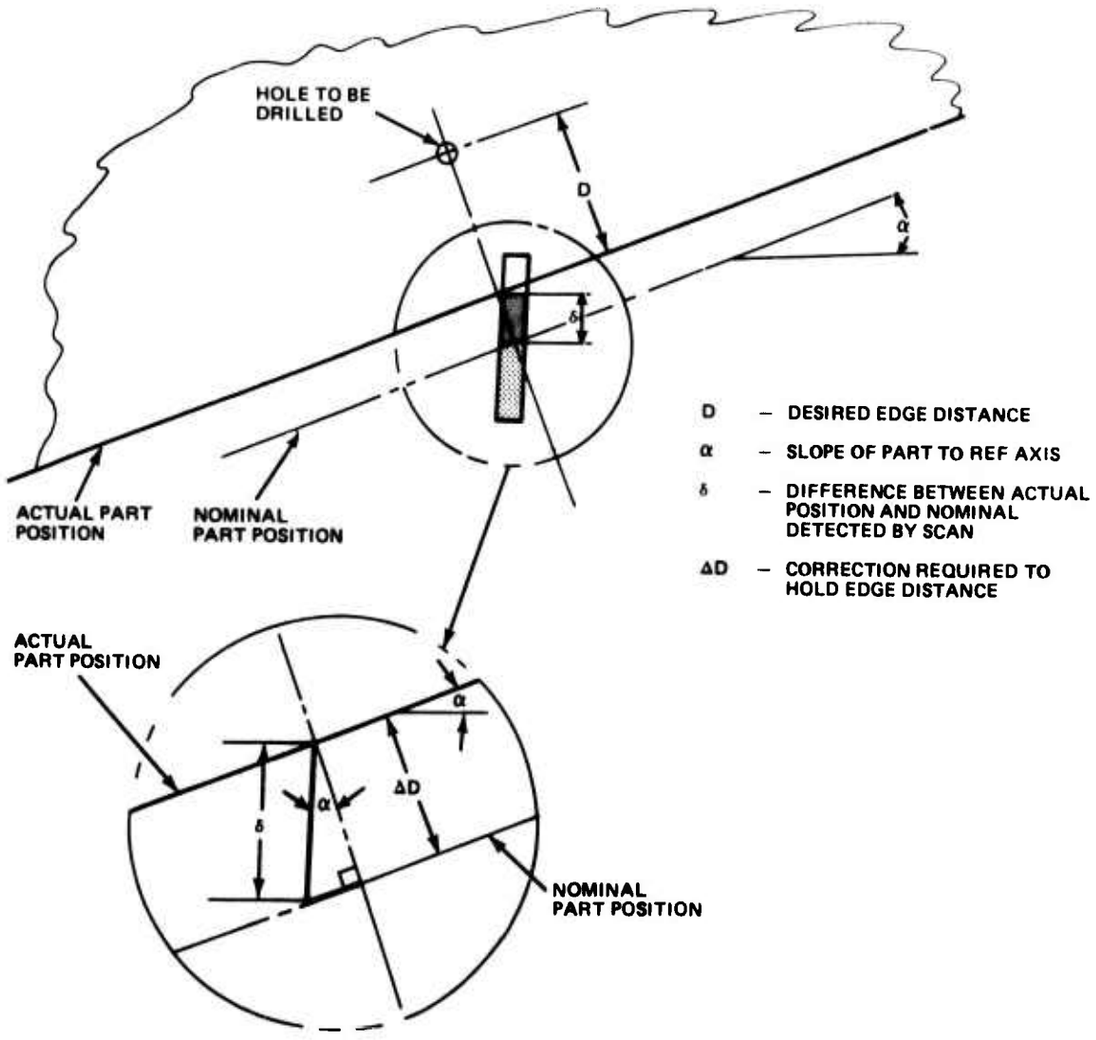


Figure 27. Scan Camera Adjustment Geometry

F. MODULAR DESIGN

The system has been designed in a modular fashion (Fig. 28) so that potential users can customize their units by properly selecting their items. The modular packages available are shown in Table 3. Some typical applications are:

- Basic Unit. To drill one component in one fixture, one of each of the items in Table 3 is required in addition to modifying the fixture with rails to accept the gantry
- Two Fixtures Drilling Two Different Components Simultaneously. One of each of the items in Table 3 plus additional B, C, D, E, G, and H items (one each), together with modifications to the fixture, are required.

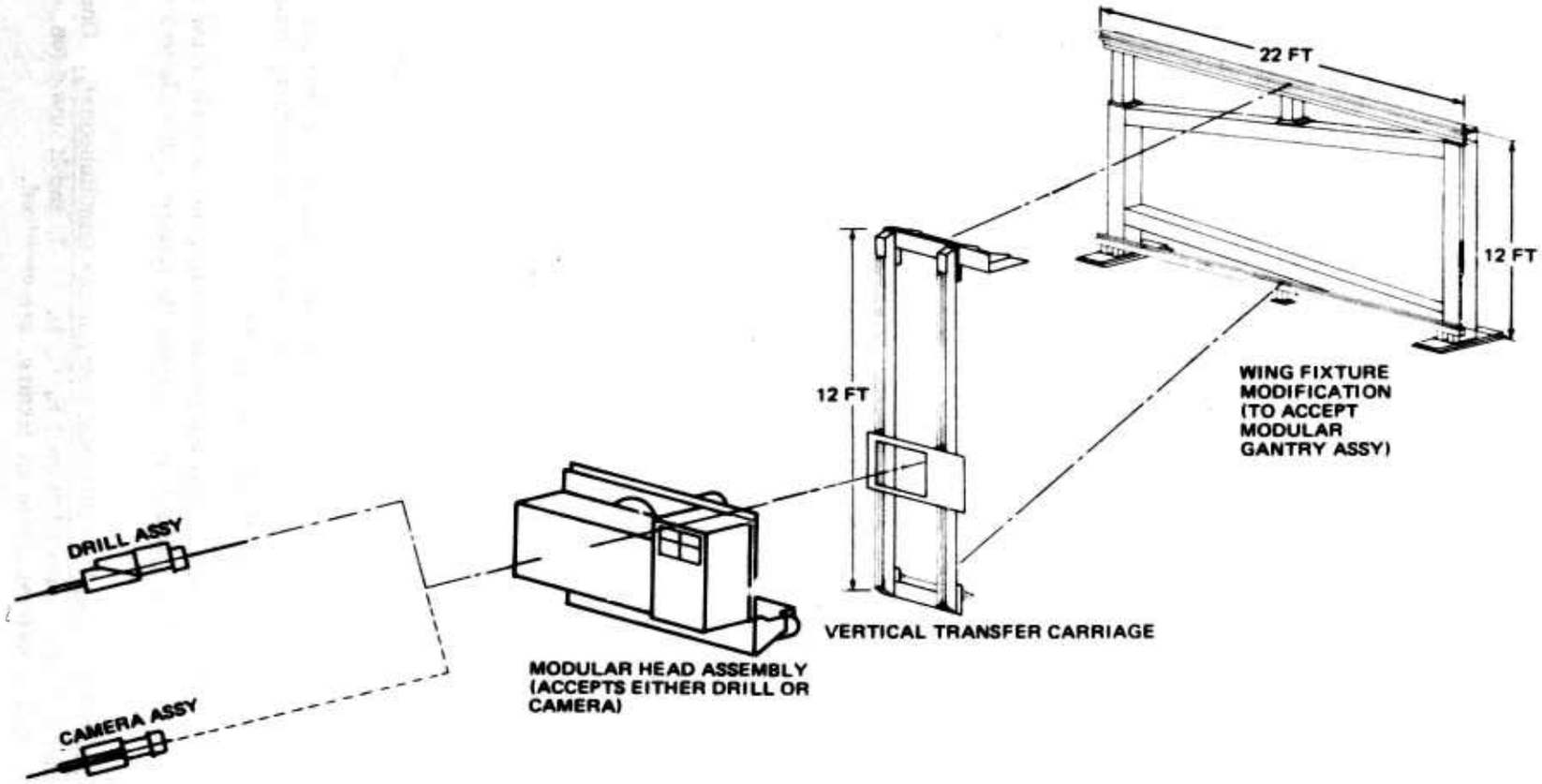


Figure 28. Modular Design Concept

Table 3. Modular Components

Item	Module	Key Components	unction
A	Central Controller	• Computer • Disc • Real-Time Clock • Serial Data Link • Power Supplies • Interface Electronics • Logic Racks & Cabinet • Teletype	Controls the motion & operation of up to eight drill units; can also be used for editing parts programmers source files
B	Drill Head Assembly	• Mechanical Assemblies Including Alpha, Beta, and Y-Drive Motors, Encoders, Z-Axis Pneumatic Cylinders, Potentiometer or Hydrocheck • Fluidic Controls • Position Displays	This unit which mounts on the gantry, holds the drill units or the scanning camera, sets the angle to be normal to the work surface, & moves the drill or scan camera into the work surface
C	Gantry	• Mechanical Assembly including X-drive Motor & Encoder, Vertical Power Track • Drive Motor Translator Cards • Cables, Connector, & Cable Disconnect Plate • Power Supplies & Power Switching Circuits	Holds the drill head & moves the head in the X-axis; is mounted to the fixture & can be moved from fixture to fixture
D	Remote Interface Box	• Serial Data Link • Interface Electronics • Power Supplies • Cabinet	This unit, which resides at the fixture it is controlling, receives data & commands from the computer, processes these, & sends & receives signals to one drill head, gantry, & operator's control pendant;
E	Operator's Control Pendant	• Control Pendant with Switches, Lights, Message Display, Thumbwheels	This unit, which hangs from the gantry, provides communications between operator & central or remote controller. Machine can be controlled manually without the computer, using the control pendant
F	Scanning Systems	• Scan Camera • Scan Controller • Camera Rotate Mechanism	Allows scanning of the substructure & digitizing of the video data. The camera is mounted inside the drill head cylinder in place of the drill unit. The scan controller is mounted in the remote interface control box
G	Drilling Unit	• Drill Unit	Drilling, countersinking, counterboring
H	Fixture Items	• Horizontal Power Track • Cables • Power Supplies for X, Y, Alpha, & Beta Motors	Set of cables to route signals & power to the gantry from the remote control unit. DC power for stepper motors

- Fifteen Different Fixtures. Assuming that the production rate is such that only eight drill units must be operated simultaneously and that only two units will be scanning at the same time, the items required are one central controller (A); eight drill head assemblies (B); eight gantries (C); eight remote interface boxes (D); eight operator control pendants (E); two scanning systems (F); eight drill units (G); and fifteen fixture items (H), together with modifications to each of the fifteen fixtures.

For large system configurations that involve significant creating, changing, and editing of the parts programmer's files, the central controller should be equipped with a second disc unit to make backup copies of the primary disc, a high-speed paper tape reader/punch (or a cassette system), and a line printer.

G. SYSTEM SOFTWARE

1. Components

The system software developed under this program consists of the preprocessor software (PPS) and the run-time system software (RTSS).

2. Preprocessor Software (PPS)

The PPS accepts the parts programmer's source file from the disc and converts it into three binary files for storage on the disc. The PPS also sets up all the mapping required to permit the RTSS to access the coordinates in a random fashion. Each of these packages is written in PDP 8/E assembler language and operates under the DEC (Digital Equipment Corporation) OS/8 system. The relationship between these packages and creation of the initial data file is shown in Fig. 29.

3. Run-Time System Software (RTSS)

a. Function. The RTSS controls the motion of up to eight 5-axis drilling gantries simultaneously and independently, such that each gantry can be working on its own part at its own pace. The RTSS operates in a polling mode as shown in Fig. 30. When it is a particular gantry's turn in the loop (and that gantry exists), an interrogation of that gantry will reveal to the RTSS whether or not that gantry needs service. If it does, the RTSS loads certain tables into core from the disc segment that has to do with that gantry and then goes about giving that gantry service. When it finishes servicing that head (or if the gantry did not require service), the RTSS switches attention to the next gantry in the loop. Most of the time the gantry will not require service, since a head does not need service while moving between holes or when drilling.

Although the RTSS basically utilizes a polling scheme, the interrupt system is enabled to detect a low-power condition at the computer and to keep track of elapsed time. The low-power condition and elapsed time are handled by the power fail card and the real-time clock card, respectively. Both of these cards are supplied by the Digital Equipment Corporation. The time-interrupt module is used to ensure that a particular gantry is not hung up in a state which should terminate in a known maximum time. Such a situation might occur, for example, if the drill failed to retract (caused, for example, by a drill breakage) or if an axis drive were inoperative.

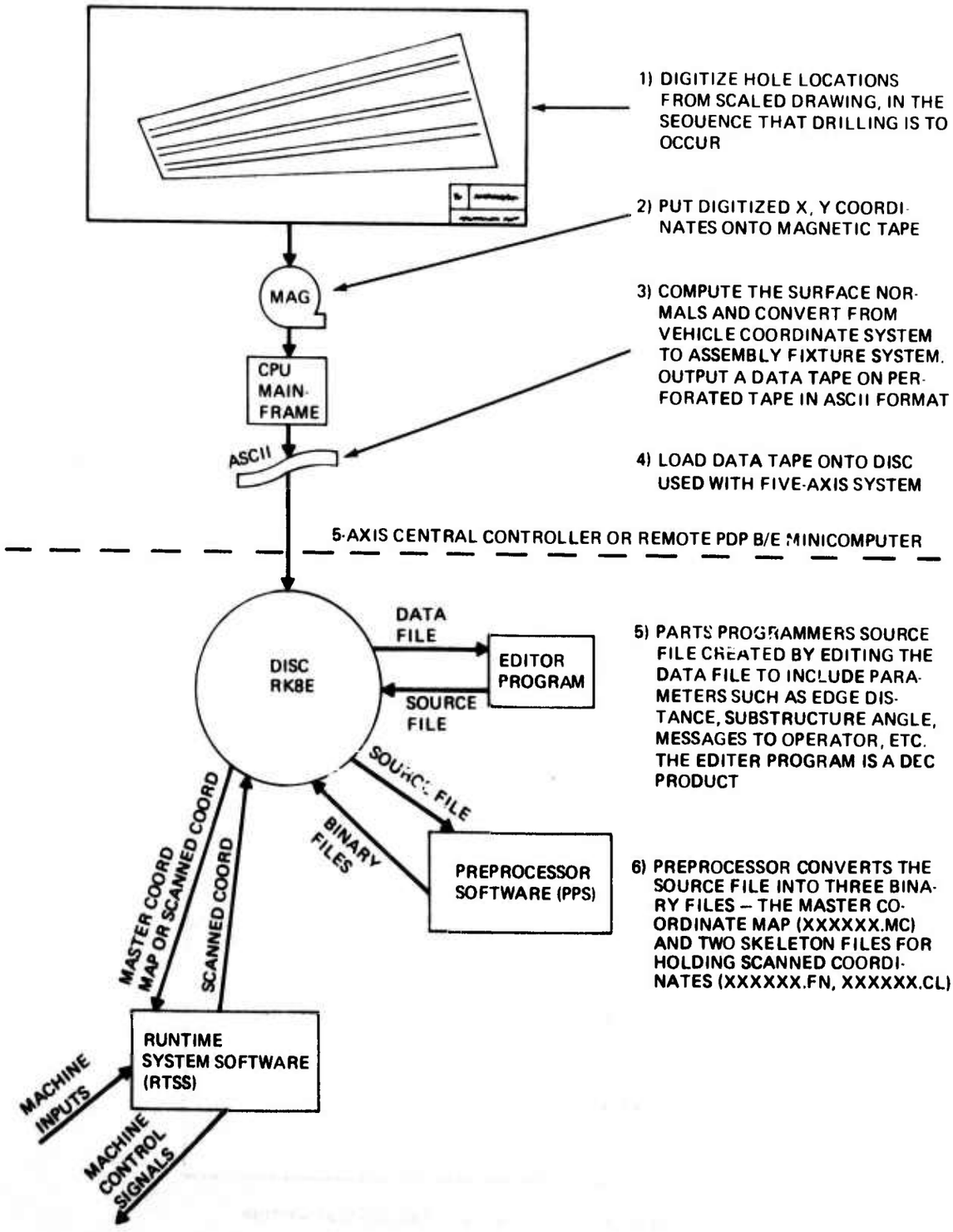


Figure 29. Overview of Data File Creation

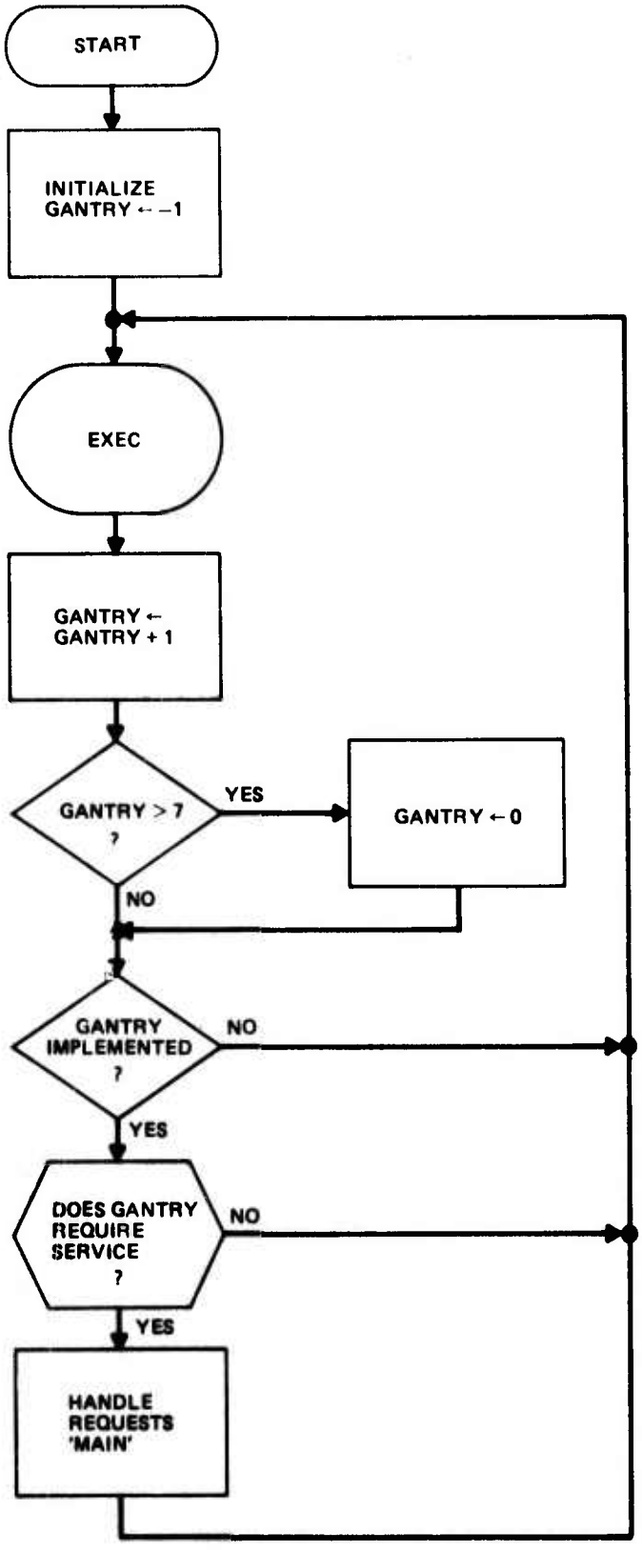


Figure 30. RTSS Flow Chart for Polling of Gantries

b. Data Base. An important consideration for any software system that is dependent upon a large amount of data is the structure of the data base. The various factors which come into play in its selection are the relative access speed required, the relative storage required, and the frequency of access methods.

Several data base systems were evaluated, including sequential lists and single- and double-linked lists. While the linked lists afforded ease of random access when combined with suitable addressing schemes, the amount of core storage required was deemed too great. In view of the fact that most accesses to the data base would be sequential (in going from the previous hole to the next), a simple linear sequential list was decided upon. However, to make random accesses possible (to a particular hole number, for example) without a time-consuming sequential search, the data are arranged in blocks (compatible with the pseudo-physical disc blocking arrangement of 256 words per block) with header information in each block. The RTSS can thus access a coordinate by giving its hole number or record number, or can find the first hole in an operation by giving an operation number.

The basic unit of information which the RTSS can extract from the data base is the record. Eight classes of records have been defined and categorized into three different data types. Data Type 0 records, which contain Data Classes 0-6, are used to store tables which are required by the RTSS for a particular part number. These tables contain drill diameters, edge distances, skin thicknesses, and dimensional offsets for each axis. The Data Type 1 records are used to carry most of the data required by the RTSS in order to determine what auxiliary functions are required. The Data Type 2 records are used to describe the actual coordinate information, as well as to carry some of the functional information. Each of these data type records is stored in a binary format consisting of ten 12-bit words. Figures 31, 32 and 33 illustrate the records for the three data types. Table 4 shows the mnemonics that the parts programmer uses to set up these various entries.

The basic unit of meaningful information, as far as the RTSS is concerned, is the segment. A segment, as structured in this data base, can be from 1 to 24 bits in length. The hierarchy of the data is shown below:

Bit - The smallest amount of data which can be stored and which contains either a zero or a one

BYTE = 8 bits

WORD = 12 bits

SEGMENT variable between 1-24 bits

RECORD = 10 words

PAGE = 128 words

BLOCK = 2 pages

FIELD 16 blocks

FILE = variable (consists of two header blocks plus at least one block of records)

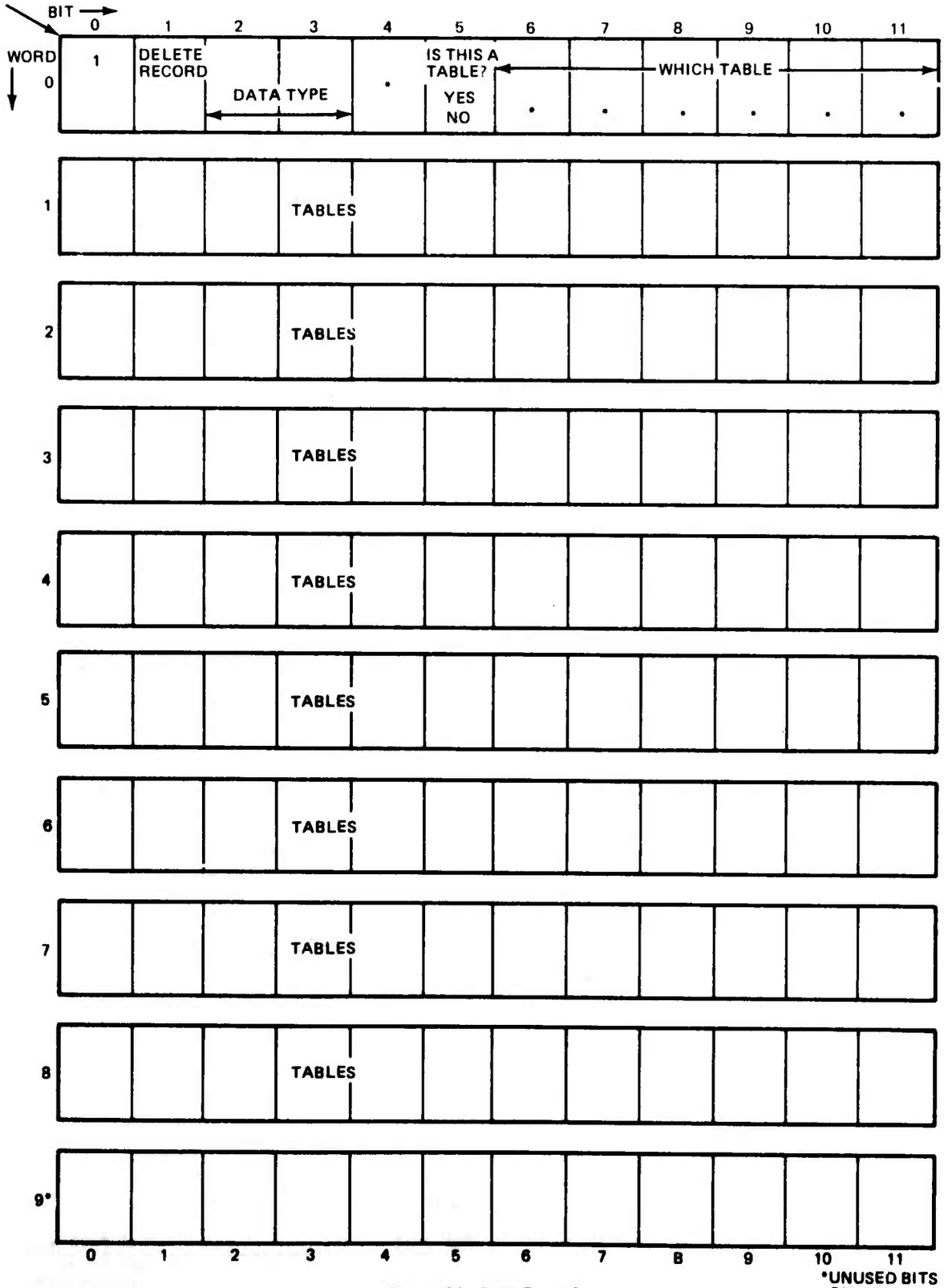


Figure 31. Data Type O

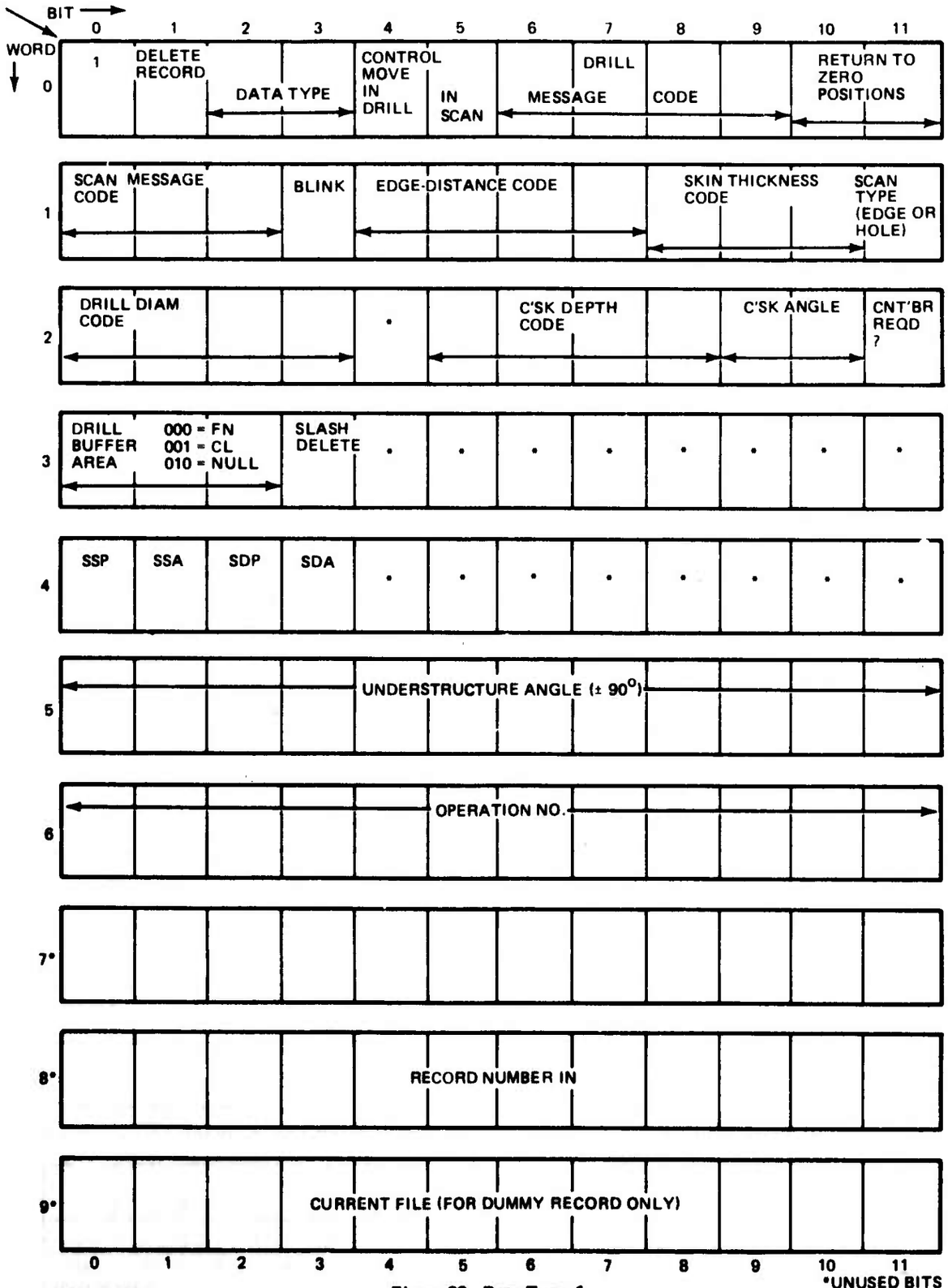


Figure 32. Data Type 1

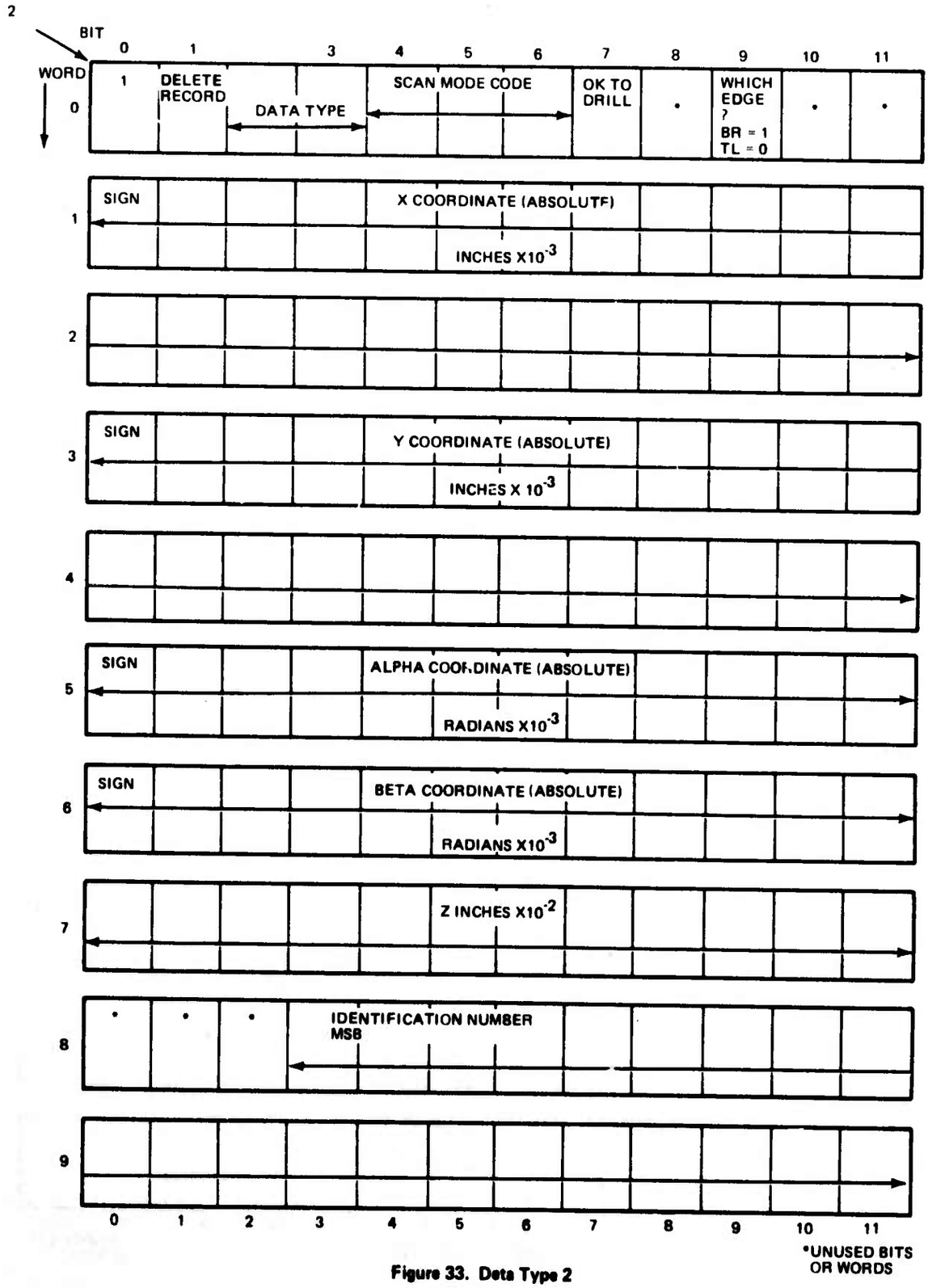


Figure 33. Data Type 2

DATA CLASS	DATA TYPE	LEXICON	MNEMONIC	DESCRIPTION	TYPE OF MNEMONIC AND HANDLER	FORMAT CODES (WHERE APPLICABLE)
0	0	C	X OFF = ± xx.xxx	x COORDINATE OFFSET (IN.)	VARG	2, d
0			Y OFF = ± yy.yyy	y COORDINATE OFFSET (IN.)	VARG	2, d
0			A OFF = ± a.aaa	ALPHA COORDINATE OFFSET (DEG)	VARG	0, d, f
0			B OFF = ± b.bbb	BETA COORDINATE OFFSET (DEG)	VARG	0, d, f
0		C	Z OFF = ± Z.ZZZ	Z COORDINATE OFFSET (IN.)	VARG	2, c
1		A	EDG1 = (-,-,-,-,-,-,-,-)	EDGE DISTANCE TABLE (ENTRIES 0-7)	PARM	1, d
2			EDG2 = (-,-,-,-,-,-,-,-)	EDGE DISTANCE TABLE (ENTRIES 8-15)	PARM	1, d
3			DRL1 = (-,-,-,-,-,-,-,-)	DRILL DIAMETER TABLE (ENTRIES 0-7)	PARM	1, e
4			DRL2 = (-,-,-,-,-,-,-,-)	DRILL DIAMETER TABLE (ENTRIES 8-15)	PARM	1, e
5	0	A	THK = (-,-,-,-,-,-,-,-)	SKIN THICKNESS COEFFICIENT TABLE	PARM	1, e
6	1	B	SM_X	SCAN MESSAGE CODE (X = 0-7)	STANDARD	
			DM_{XX}	DRILL MESSAGE CODE (XX = 0-15)	STANDARD	
			RTZ_X	RETURN TO A ZERO POINT (X = 0-3)	STANDARD	
			STP_X	SCAN TYPE (X = 0 OR 1)	STANDARD	
			ED_{XX}	EDGE DISTANCE CODE (XX = 0-15)	STANDARD	
			ST_{XX}	SKIN THICKNESS CODE (XX ⇒ X.X) (LEGAL VALUES OF X.X TO BE DEFINED)	STANDARD	
		B	DD_{XX}	DRILL DIAMETER CODE (XX = 0-15)	STANDARD	
		D	HOLE	FOLLOWING COORDINATES TRANSFERRED TO FINISH) HOLE FILE '.FN'	STANDARD	
			TACK	FOLLOWING COORDINATE TRANSFERRED TO CLECO HOLE FILE ',CL'	STANDARD	
			DUMY	FOLLOWING COORDINATES NOT TO BE TRANSFREEED TO A FILE	STANDARD	
			fCTB	COUNTERBORE REQD (CTB) NOT REQD (fCTB)	FLAG	
			fSLS	SLASH DELETE FEATURE ON (SSL), OFF (fSLS)	FLAG	

				(XX = 0-15)			
			RTZ_X	RETURN TO A ZERO POINT (X = 0-3)	STANDARD		
			STP_X	SCAN TYPE (X = 0 OR 1)	STANDARD		
			ED_{XX}	EDGE DISTANCE CODE (XX = 0-15)	STANDARD		
			ST_{XX}	SKIN THICKNESS CODE (XX ⇒ X.X) (LEGAL VALUES OF X.X TO BE DEFINED)	STANDARD		
		B	DD_{XX}	DRILL DIAMETER CODE (XX = 0-15)	STANDARD		
		D	HOLE	FOLLOWING COORDINATES TRANSFERRED TO FINISH) HOLE FILE '.FN'	STANDARD		
			TACK	FOLLOWING COORDINATE TRANSFERRED TO CLECO HOLE FILE '.CL'	STANDARD		
			DUMY	FOLLOWING COORDINATES NOT TO BE TRANSFREEED TO A FILE	STANDARD		
			fCTB	COUNTERBORE REQD (CTB) NOT REQD (fCTB)	FLAG		
			fSLS	SLASH DELETE FEATURE ON (SSL), OFF (fSLS)	FLAG		
			fSSP	STOP (IN SCAN MODE) PRIOR TO SCANNING (SSP) DON'T STOP (fSSP)	FLAG		
			fSSA	STOP (IN SCAN MODE) AFTER SCANNING (SSA), DON't STOP (fSSA)	FLAG		
			fSDP	STOP (IN DRILL MODE) PRIOR TO DRILLING (SDP) DON'T STOP (fSDP)	FLAG		
			fSDA	STOP (IN DRILL MODE) AFTER DRILLING (SDA) DON T STOP (fSDA)	FLAG		
			fCMD	CONTROL MOVE IN DRILL MODE (CMD), NOT A CONTROL MOVE (fCMD)	FLAG		
		D	fCMS	CONTROL MOVE IN SCAN MODE (CMS), NOT A CONTROL MOVE (fCMS)	FLAG		
		C	ANGL = ± XX	UNDERSTRUCTURE ANGLE (DEG)	VARG	0, a	
6	1	C	OP = XX	OPERATION CODE (XX = 1-64)	VARG	1, a	
7	2	B	SCN_X	SCAN MODE CODE (X = 0-3)	STANDARD		
		C	N yyyyy.yyy,	INTRODUCES A COORDINATE SET (0-5 COORDINATES PLUS AN OPTIONAL COORDINATE NUMBER (#) AND AN OPTIONAL SEQUENCE NUMBER (yyyyy.yyy)	COORD	2, d (x & y) 0, d (a & B) 2, c (Z)	
7	2	D	EG_{zz}	EDGE DESIGNATORS ZZ = TL ⇒ TOP OR LEFT EDGE ZZ = BR ⇒ BOTTOM OR RIGHT EDGE	STANDARD		
		D	END	SIGNAL TO PREPROCESSOR THAT THIS IS THE END OF THE THE INPUT FILE	FINI		

Table 4 Mnemonics for Parts Program

The records are arranged in groups of 24 and stored on a disc block together with a dummy record and block header information. A file which totally describes an effort (such as the scanning effort, finish-hole drilling effort, or Cleco hole drilling effort) consists of these record blocks and two additional header blocks. This format is shown in Fig. 34. The two header blocks, as well as the record block header information, are used to describe the file to the READ/WRITE modules. The RTSS itself is not concerned with any of this header information nor can it gain access to it.

There are three types of files of interest to the RTSS. The first, known as the Master Coordinate File, contains the information required during the scanning of the part. It contains the position of each coordinate to be drilled and/or scanned, as well as all auxiliary information. Since this is a shared-date file, it references coordinates on the surface of the workpiece rather than at the center of the spherical bearing. The transformation to the spherical bearing is made by the RTSS with the aid of the descriptor tables for the appropriate drill head. The Master Coordinate File is designated with a file-type of 'MC' appended to the end of the file name (described in following section).

The second type of file is called the FINISH hole file and consists of all those holes that would normally be drilled and countersunk in one operation. This file has a file-type of 'FN'. The third file-type is the CLECO hole file and consists of all those holes and associated auxiliary information for the group of holes that are normally drilled first so that temporary tack hardware can be inserted to hold the skin to the understructure. This file has a file-type extension of 'CL'.

c. File Names and File-Types. The file-naming procedure adopted was chosen to be compatible with the DEC OS/8 software package. This software allows a file name of up to six alphanumeric characters followed optionally by a period and an extension of up to two alphanumerics. Thus, the following are all proper file names:

FILE 22

F. 14

Z

TESTFI. LE

BISTBL. ZR

A10

The RTSS is restricted to a subset of allowable names. The format followed in the RTSS scheme is that all files have a six-character file name, the fourth to designate the drill gantry used, the fifth an alpha to specify the fixture to which it applies, and the sixth numeric to reflect the drill head (1-8) used when creating the file. In addition, a file-type will be required consisting of one of the following: '. MC', 'FN' or '. CL'. In cases where the file is to be used by several heads and/or fixtures (such as a file with an '. MC' file-type extension), the fourth, fifth, and sixth characters of the file-name will be ZZ9'.

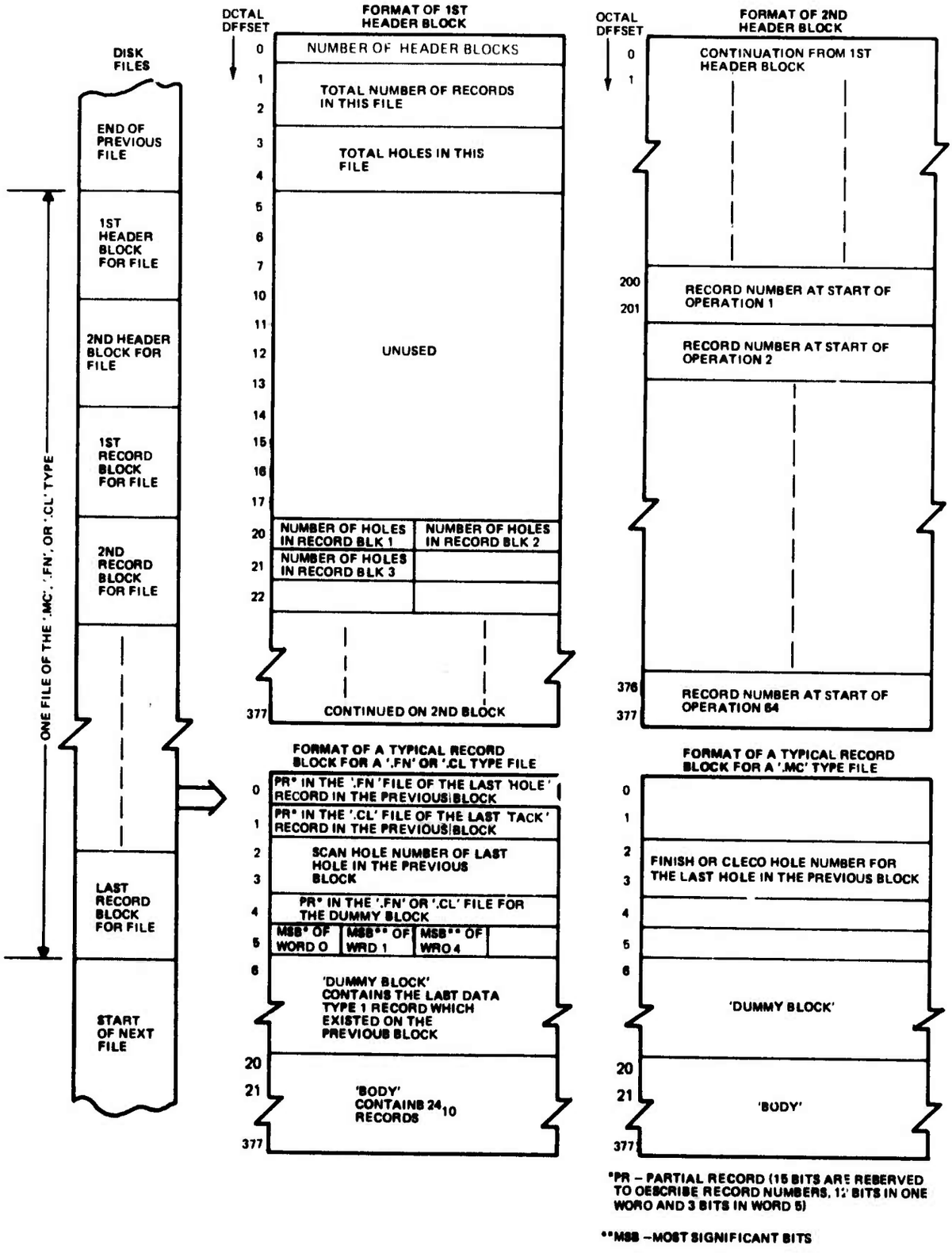


Figure 34. File Format

The arrangement of the files on the disc can be seen by examining Fig. 35. Each structure which has been programmed by a parts programmer will have at least three files associated with it. One, with the file-type of . MC, is the master coordinate map and is shared by all fixtures which are used for that part. It is accessed in the scan mode by the RTSS using the READ construct discussed below. The RTSS does not write to this file except during special test modes. Of the other two files, one has an . FN file-type and the other a . CL file-type. These are skeleton files and contain all the auxiliary commands and header information required by the READ and WRITE modules. These skeleton files are used to create a user file for a particular head. Although all of the information is there to drill a part, each coordinate is rendered inoperable by a flag bit (Bit 7 of Word 0 of Data Type 2) being set to zero for all coordinates. The RTSS sets this bit to a '1' after it has operated on that coordinate in the scan run.

The file management system is handled by a group of modules which insulate the RTSS from the details of disc transfers, buffering, file directories, auxiliary storage and Input/ Output to the machine. The file management system consists of READ, WRITE, CLOSE, CLEAR, STORE, INPUT and OUTPUT modules. Opening of a file is implicit with the first READ or WRITE access to the file. The file management modules, in turn, interface with the actual disc drives through the OS/8 software supplied by DEC. This interrelationship of physical devices and software is shown in Fig. 36.

d. System Software Definitions. The system software architecture has been optimized for ease of understanding and modification. It is written in machine language and compiled by using the DEC PAL-8 compilation program. The software is sectioned into small modules that perform a single function or operation. Each module's field, starting location, and externally referable locations are defined mnemonically in a separate parameter

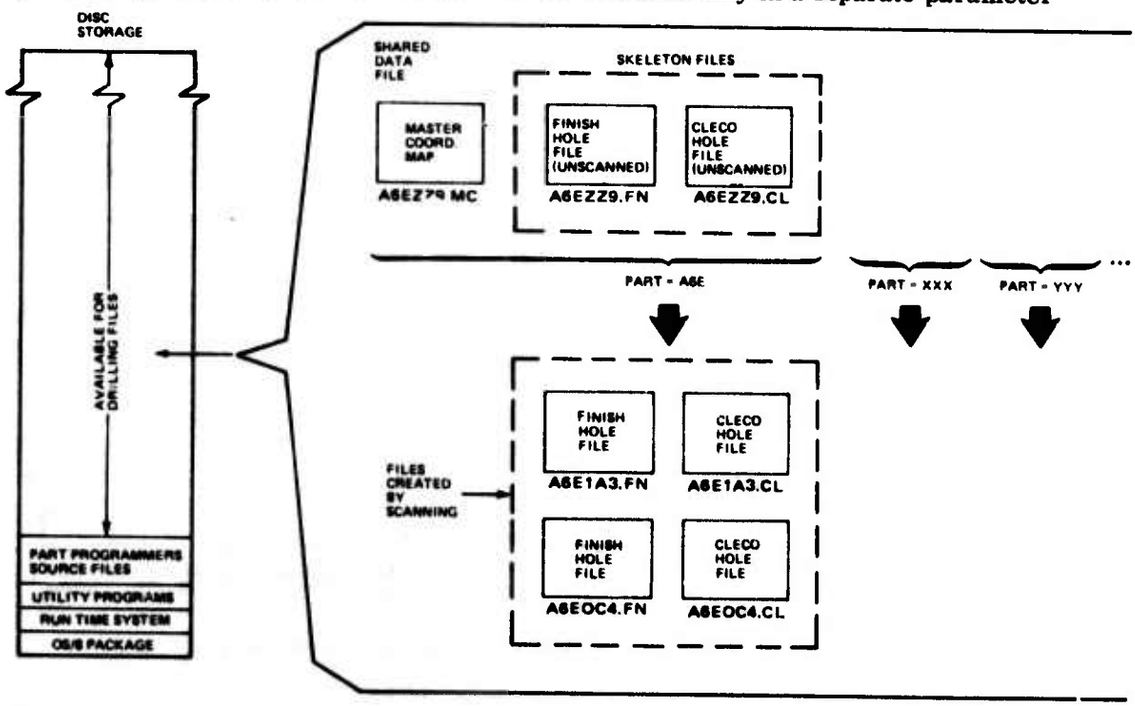


Figure 35. Typical File – Memory and Disc Storage Allocation

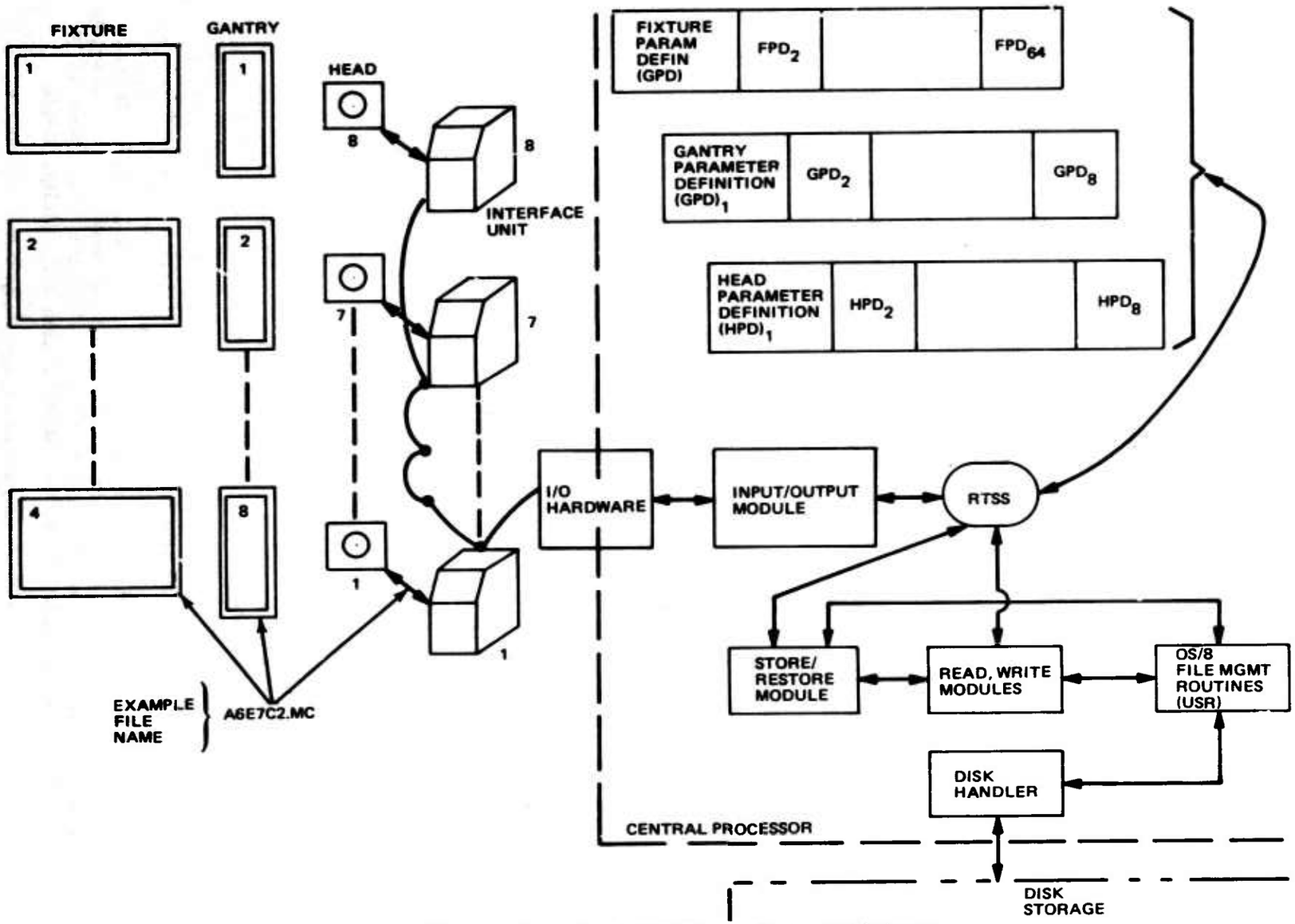


Figure 36. Interrelationship of RTSS Physical Devices and Software

file. References external to any module are always given mnemonically utilizing the definitions contained in the parameter file. When a module is to be modified or relocated in core, the appropriate redefinitions need only be entered once in the parameter file to modify all references to the module in the real-time system software.

(1) Modules. A module is defined as a contiginous group of instructions that perform a single function or operation. Four basic types of modules are used in the system.

- Routine. One that is entered from another module via a JMP or JMP indirect instruction. The contents of the module are lost and the routine makes an attempt to return to the original module (i. e., EXEC module)

- Subroutine. One that is entered from another module via a JMS or JMS indirect instruction. The entered module retains the PC and field of the previous module and will return to the previous module if it can complete its function or operation

- Call. One that will relinquish control to the executive monitor upon completion of its function but must have the calling module re-entered when the user again becomes active. It is reached via an intermediate module named CALL. CALL supervises the log-in of the calling module's return field address into a push-down stack and the transfer of parameters to the called module. The called module (e.g., AWAIT) initiates an operation and transfers control to the monitor so that other users can be serviced. When the operation is complete, control is returned to the users' calling module via the DONE module which pops the stack to obtain the calling module's field location

- SWAP. One that is disk-resident and is only placed in core when needed. These modules are reached via the MSWAP module which supervises the implementation of SWAP modules in the SWPBLIK are of core.

(2) Core-Resident Tables and Buffers

- CBUF. CBUF is the system storage area. It contains all user states, clock counts, abort addresses, and flags. In addition to user parameters, CBUF contains the current active user number, current disk message block in core number, current GTMP in core number, resident module swapout flag, interrupt save registers, and disk error messages. Each set of user parameters in CBUF has a mnemonic address defined in the parameter file. To obtain the value of a given user's parametor, the system indexes into the mnemonic parameters by the value of the user's number (e.g., the major state of User 3 is located at MAJST + 3)

- GBUF. GBUF is a core buffer that contains an overlayed image of the user's disk-resident GTMP file. It contains all of the user's non-volatile parameters. The number of the user whose GTMP is currently in GBUF is located in CBUF. When a new user becomes active, the previous user's GBUF is written into the previous user's GTMP disk area and the new user's GTMP is overlayed from the disk into GBUF. During the time the user is active, the user's GBUF values are used or modified as required by the system software. As with CBUF, all value addresses in GBUF are defined mnemonically in the parameter file. However, no indexing is required since only one user occupies GBUF at a time. Since GBUF currently occupies 140 locations, this method of user disk overlays results in

the saving of more than a field of core and yet provides an efficient method of running eight users

- CALTAB. The CALTAB module is a table of callable modules that are accessed through the CALL module. Entries consist of the mnemonics for the module's field and address, along with a "J" parameter defining the number of parameters to be passed from the calling module

- CNTAB. The CNTAB module is a table of code number modules. Module entries contain the mnemonics for the module's field address. Code number modules are service modules for handling operator-requested functions defined by a code number from the operator's pendant. The CNTAB module is used by the DISP module.

- DPTAB. The DPTAB module is a table of modules that display information to the operator on the operator's pendant. Entries to the table consist of the mnemonics for the module field and address. DPTAB is used by the DISP module as a lookup table.

- MSPTB. The MSPTB table of modules that normally reside on disk are seldom used and, hence, are only brought to core as required. Entries to the table consist of four words. The first two words are the parameter defined mnemonics for disk, block and module core address. The third is a composite word containing the module's flag, field, and parameter count. The fourth word contains the return address mnemonic, if the module does not return to the calling module.

(C) User States. Each user's current status is defined by a major and a minor state number. These numbers are updated as the user progresses through the various states. The state values are utilized by the executive monitor to determine the user's status. They are also utilized by system modules to check if an operation is logical or is qualified to branch-point decisions.

Value	Major State
ø	Uninitialized User
1	Initialized User Not Commanded
2	At Least One Axis in Motion
3	Awaiting Clock Flag
4	Abort/Stop State
5	Awaiting Scan Complete
6	Awaiting Drill Complete
7	Awaiting Axis Done

Value	Minor State
+1	User Initialized
ø	User initialized but not in Auto Run
-1	User Initialized & in Auto run

(4) Executive Monitor Operation. When the RTSS is powered up from a cold start, it begins by designating each user's major state as uninitialized in the system reference tables. Control is then passed to the EXEC module which checks an internal table for each of the eight possible users to determine if there is a physical gantry attached to the system. A non-zero entry in the table indicates that a gantry is attached. When an implemented gantry

is found, control is passed to the MAIN module to see if the gantry requires service. The MAIN module first checks to see if machine power is on. If not, it informs the operator and returns to EXEC. If machine power is on, the MAIN module uses the INPUT module to read the head status register. If a read error occurs at this time, the MAIN module defaults to EXEC, but will continue to try each time the user becomes active. If the MSR read is good and any bit in the register is non-zero, the MAIN module will branch to JUMP to determine the operations required. If the register is zero, the MAIN module checks the user's clock time-out flag to ensure that a previous operation has not taken longer than the maximum permissible time. If the MAIN module finds the flag set, it branches to CLOUT to handle this condition; otherwise control is returned to EXEC.

The JUMP routine checks each of the head status bits in order of priority and branches to the appropriate handler if it finds a condition to be true. The modules referenced may return to the JUMP module or may follow other routes that ultimately lead back to EXEC. For example, "Power Low" will always result in an abort to EXEC, while "Nosepiece Not Normal" will abort only on a user major state = 6 (awaiting drilling complete). If the user is not drilling, the bit is ignored and control is returned to JUMP to check the remaining possible conditions.

e. Gantry Communication. All of the I/O transfer to the machine gantries is handled by an I/O handler module. The module accepts a 12-bit data word and a 12-bit address word from the RTSS. It sends these words to the output register hardware consisting of two M1703 cards. These 24 bits are sent out serially over a coaxial line driven by the standard interface unit (SIU), a Grumman-designed and built multiplexer which operates in the 500 to 1000 KBAUD range. The coaxial line visits each gantry in a multidrop fashion. The information is received by each gantry but only the one that is addressed responds. Its response is sent back along the same line and received by input registers after being processed by the SIU.

For output transfers, that is, information to be loaded into the gantry interface logic, the I/O module verifies that the information gets loaded properly by reading the output of the affected register. This "read after load" is handled automatically by the hardware. If an error in transmission occurs, the I/O software attempts to reload the data. If, after a stipulated number of times, the data cannot be loaded properly, a fatal error condition is returned to the RTSS. The RTSS will then attempt to give a message to the operator on the self-scan display in the control pendant. If this cannot be done, a message is typed on the system teletype if one is present. The RTSS then returns to the executive which, in turn, services the next gantry.

For input transfers, the I/O module will read the register a minimum of two times and compare the results. If the two are different, a third read is performed. If a match can be made on these data, the data are accepted and the I/O module passes the data (the data that had the match) to the RTSS and also signals a non-fatal error condition. If a two-out-of-three match cannot be made, the sequence is repeated again. This continues until proper data can be returned, or until the stipulated number of tries have been exceeded. It has been estimated that with this voting technique, a device with a basic error rate of 1 in 100 can be reduced to one having an effective error rate of 1 in 40 million. For output where no read after load is required (such as a character to the self-scan display), no attempt is made to verify the transmitted data.

4. Pre-Processor Software (PPS)

The pre-processor software (PPS) accepts source files on the disc and creates the three files (the .MC shared data file and the two skeleton files, .FN and .CL) required by the RTSS and accessed via the READ and WRITE modules. An example of part of a source file is shown in Fig. 37.

Once the source file is on the disc, the PPS is called and given the source file name and the name of the master coordinate file it is to create. This sequence is illustrated by the following:

.R PPS

*A6EZZ9.MC<TEST

The characters typed by the system are underlined, while the others are typed by the parts programmer. The programmer terminates each line with a carriage return. The parts programmer calls the PPS by typing R (for RUN) and the program name, in this case PPS. The PPS calls the OS/8 command decoder which allows the parts programmer to specify the master coordinate file name to be created (A6EZZ9.MC) and the name of the source file (in this case TEST). When the PPS is finished, it will exit to the keyboard monitor which will print a period and await further commands. A directory listing of the disc at this time would show that three new files exist: 'A6EZZ9.MC', A6EZZ9.FN', and A6EZZ9.CL'.

The parts programmer's source file consists of auxiliary instructions which describe what to do with succeeding coordinates or what to do when arriving at succeeding coordinates. The auxiliary information is requested in a mnemonic form. A complete list of the currently defined mnemonic and their interpretation is shown in Table 4.

A coordinate set is introduced by a mnemonic consisting of a single 'N'. The coordinates themselves are prefixed by a letter (X, Y, A, B, or Z) to denote which coordinate is referred to. The coordinates can be given in any order desired, and for coordinates which are not explicitly given, the last defined value for that axis is assumed (coordinates are modal). This format (Fig. 37) is an improvement over the format used for the single-user software (Fig. 38) which required that the coordinates be given in a specific order, one to a line, and that coordinates be listed even though their value did not change.

A coordinate set also contains two additional fields which are optional: a sequence number field and an identify number field. The sequence number field is used to provide a sequencing which the parts programmer can use as an aid in visually searching the source listed. Since the sequence number is not passed along when the binary records are formatted, the RTSS has no knowledge of the sequence numbers. If the parts programmer begins his sequence numbering at 1 and increases by 1 for each non-control move coordinate, the resulting numbering will correspond to the implied hole numbering used by the RTSS during the scan mode. The second optional field (the identification number) is passed along to the binary records and can be displayed on the operator's pendant. Its function is to provide a unique tag to each coordinate, a tag that will not change even though the order of the coordinates may be shuffled by the parts programmer.

All of the mnemonics are modal and need to be listed only when a change in that auxiliary function is required. The mnemonics can be given in any order, and are separated by a comma, end-of-line, or a semi-colon. The source file can be commented in the same way that assembler language source programs are commented, that is, text after a '/' out

IBM

FORTRAN Coding Form

PROGRAM

PROGRAMMER | DATE | PUNCHING INSTRUCTIONS | GRAPH | PUNCH

COMM.	STATEMENT NUMBER	CONT.	FORTRAN STATEMENT
			/ THIS IS A COMMENT. THE PPS WILL IGNOR
	ED1,		DD1, EGBR, ANGL=3, RTZO, FCND, SKIO, DBFC,
		N1,	X13.75 Y8.378 A0.102 B-0.0
	SMC1,		
		N2,	X14.834 Y8.512 A0.101
	CND,		SMC2
		N2.1,	X35.14 Y9.469
	FCMD,		SMCO,
		N3,	X35.139 Y9.511
	SMC1,		
		N4,	X36.139 Y9.571
	SMCO,		
		N15,	X129.618 Y14.768
	SMC1,		
		N16,	X131.056 Y14.839
	SMCO,		
		N17,	X132.387 Y14.914 A0.100
	END		

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49

*A standard card form, IBM electra 888157, is available for punching statements from this form

FORTRAN Coding Form

GX28-7327-6 U/M 050**
Printed in U.S.A.

	DATE	PUNCHING INSTRUCTIONS	GRAPHIC								PAGE OF
			PUNCH								CARD ELECTRO NUMBER*

FORTRAN STATEMENT | IDENTIFICATION SEQUENCE

```
T. THE PPS WILL IGNORE THIS                                                    10
O, FCND, SKIO, DBFC, FSDP, DMO, SCNO,                                          20
78      AO.102      B-O.027      Z7.948      #     .10 ;                       30
                                                                               40
12      AO.101                   Z7.968      #     20 ;                        50
                                                                               60
69                               Z6.494      #     30 ;                        70
                                                                               80
11                               Z8.398      #     40 ;                        90
                                                                               100
71                               Z8.427      #     50 ;                        110
                                                                               120
768                              Z10.429     #     60 ;                        130
                                                                               140
839                              Z10.458     #     70 ;                        150
                                                                               160
914     AO.100                   Z10.479     #     80 ;                        170
                                                                               180
```

**Number of forms per pad may vary slightly

Figure 37. Typical Example of Part of a Source File

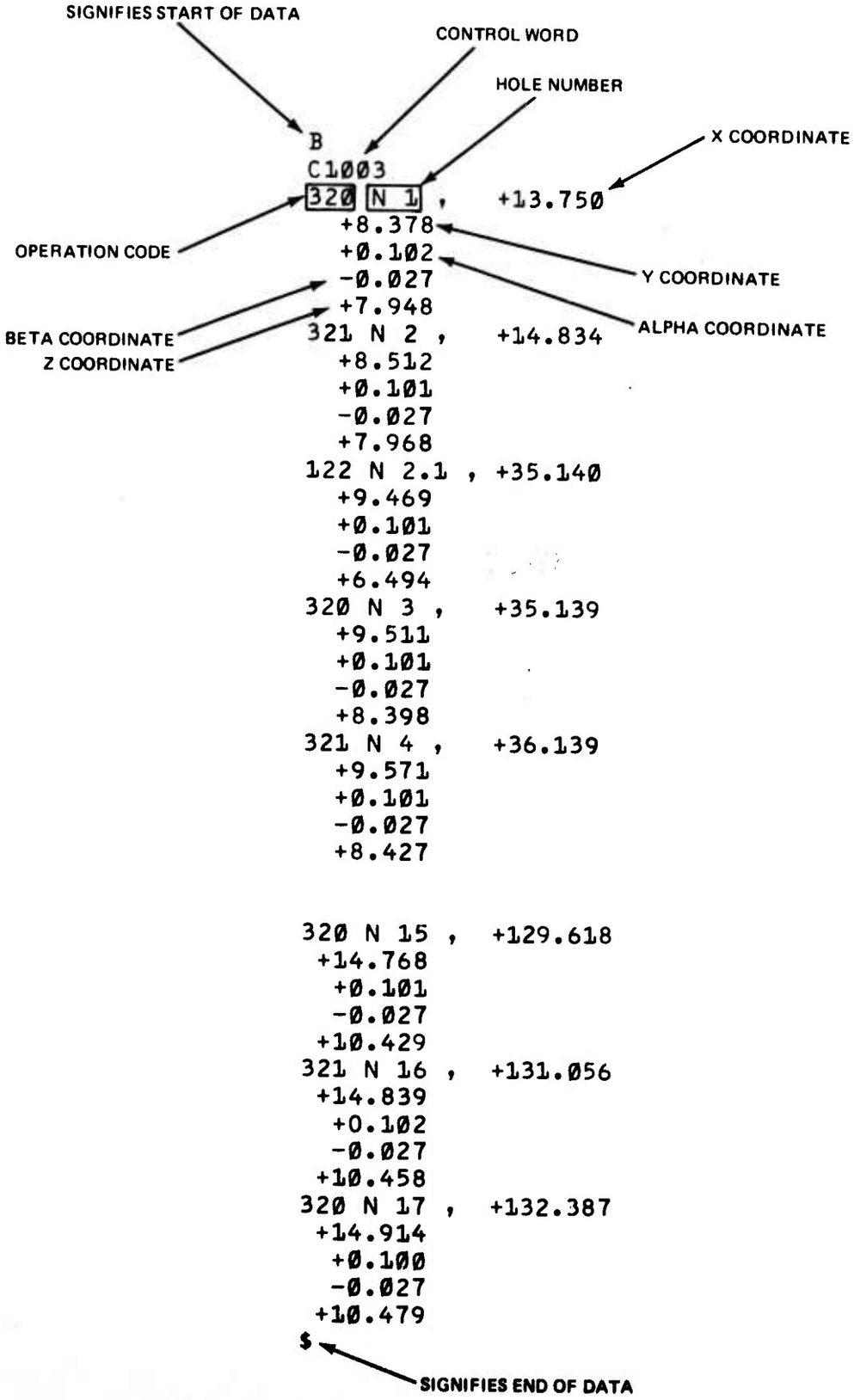


Figure 38. Format for Single-User Parts Programming

to the end of the line is a comment. The complete syntax for the source language is shown in Fig. 39.

The PPS was created using top-down programming. This is a systematic breakdown of a problem into increasingly more detailed segments usually recorded in the form of flow charts. In top-down programming, the control architecture statements and initial data definitions are specified prior to the development of the functional units. As contrasted to bottom-up programming, top-down affords such advantages as ease of integration and check-out, and ease of understanding (programs become more readable).

The systematic dissection of the PPS is illustrated by the partial flow charts for the PPS shown in Fig. 40 through 49. The functions of major routines are as follows:

- Popkar - Pops the next character from the designated source file on the disc. The character is in 8-bit ASCII format. Popkar does not respond to or return: blanks, carriage return, spaces, leader-trailer, tabs, form feeds, or rubouts. The routine has a one-character push capability so that a character may be saved by pushing it back onto the stack

- Scanner - Forms the mnemonic words by retrieving characters via calls to Popkar. It does some syntax checking but does not determine if the mnemonic is valid

- Lookup - Performs a sequential lookup in one of four lexicons. When found, the attributes of that mnemonic are returned as global variables

- Standard - A handler for a group of mnemonics known as standard mnemonics. These mnemonics are typified by having a digit as their last character and not being followed by a '='

- Varg - A handler for a group of mnemonics known as argument mnemonics. These mnemonics are typified by having a '=' as the next character but not a '(' following the '=';

- Parm - A handler for a group of mnemonics known as parameter mnemonics. These mnemonics are typified by having a '=(' after the mnemonic

- Cord - A handler for dealing with coordinate sets. This is typified by a single 'N' character mnemonic

- Checkout - Causes the binary 10-word records to be written out onto the disc by calling a special write module (SPWRITE)

- Spwrite - Writes a record onto the disc after filling up a core buffer. Attaches the block header words. Also forms the two-block file headers required

- Fini - At the end of the source input file, this routine creates the skeleton files with the . FN and . CL file-type extension.

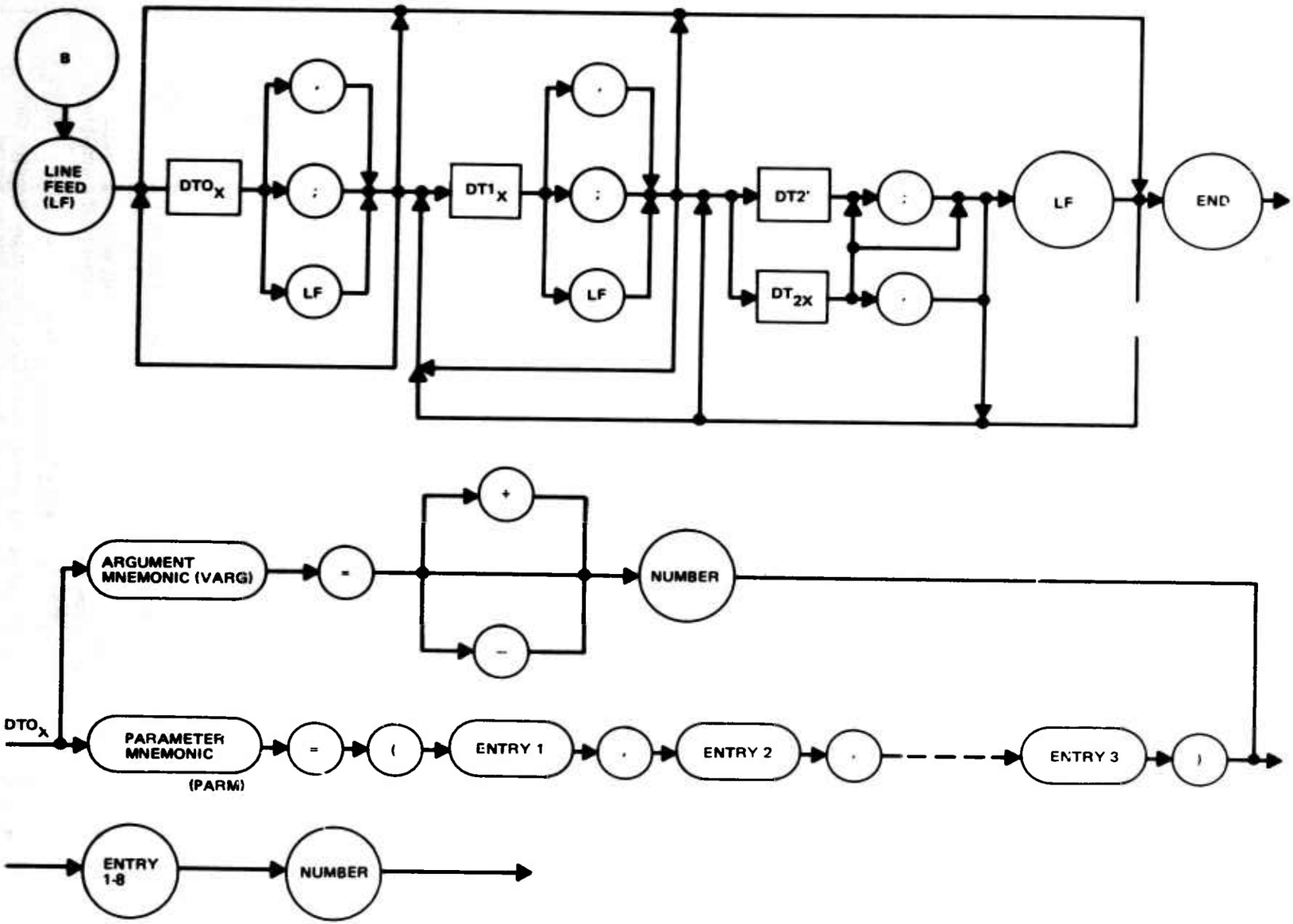


Figure 39. Syntax for PPS Source Language (Sheet 1 of 3)

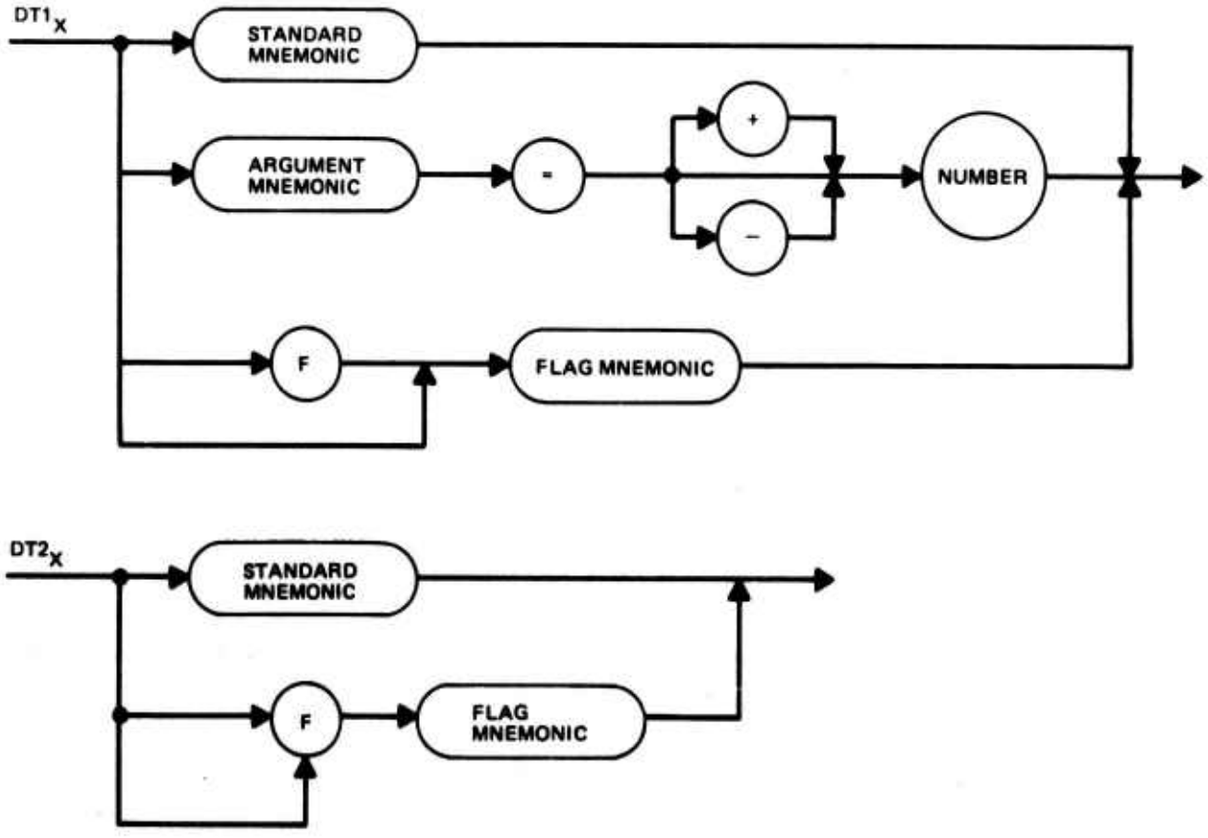


Figure 39. Syntax for PPS Source Language (Sheet 2 of 3)

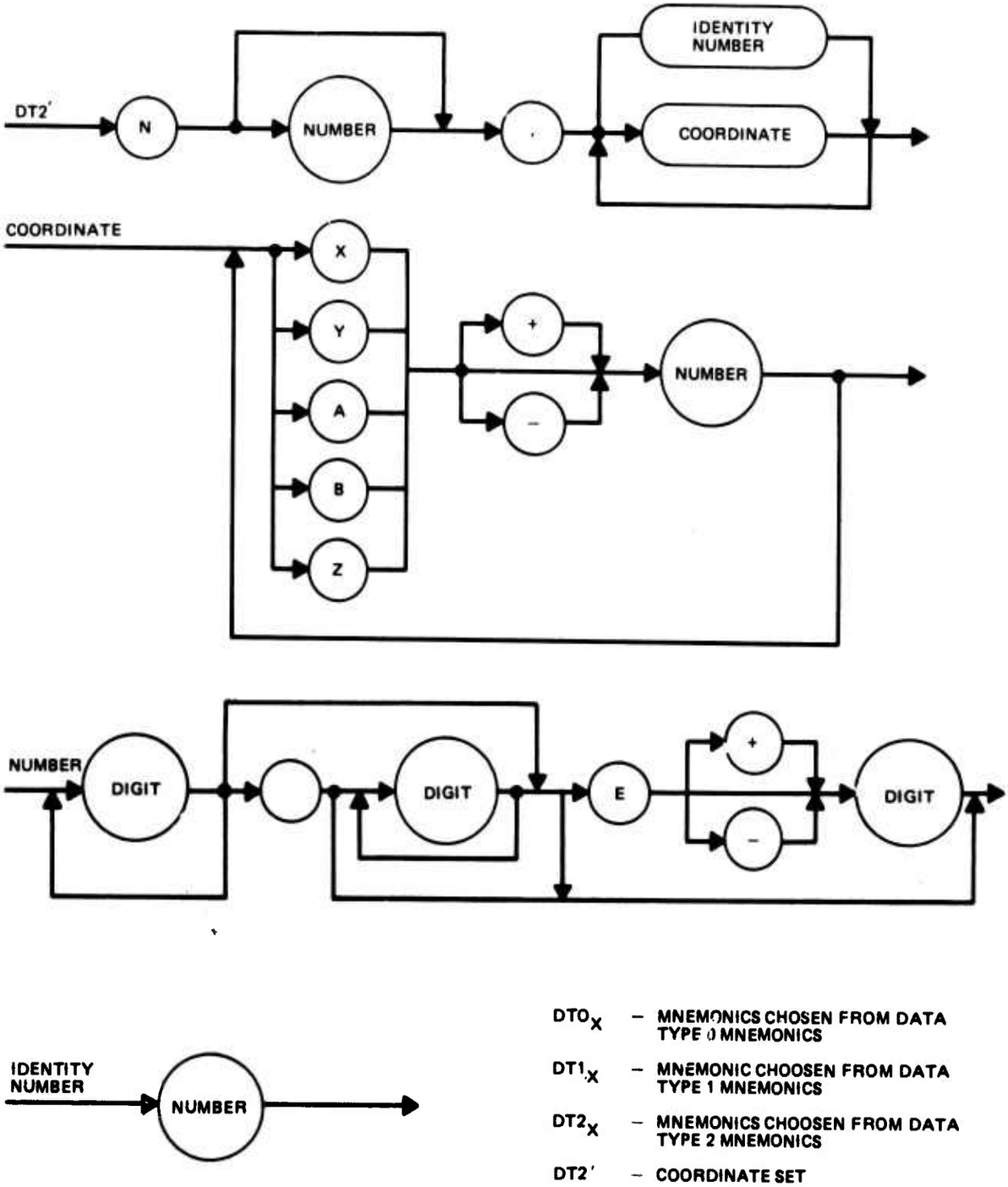


Figure 39. Syntax for PPS Source Language (Sheet 3 of 3)

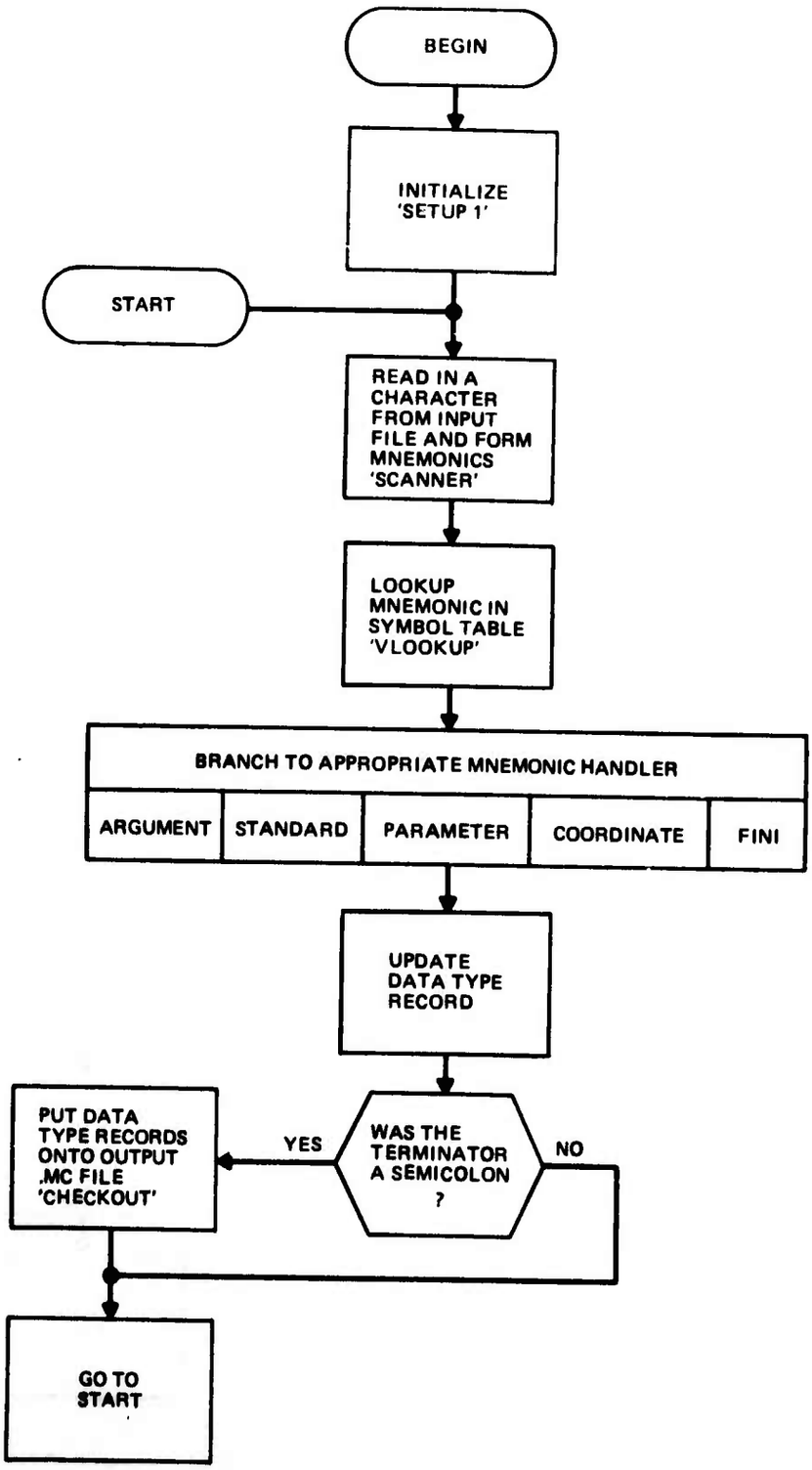


Figure 40. Dissection of Parts Programming Software – Step 1

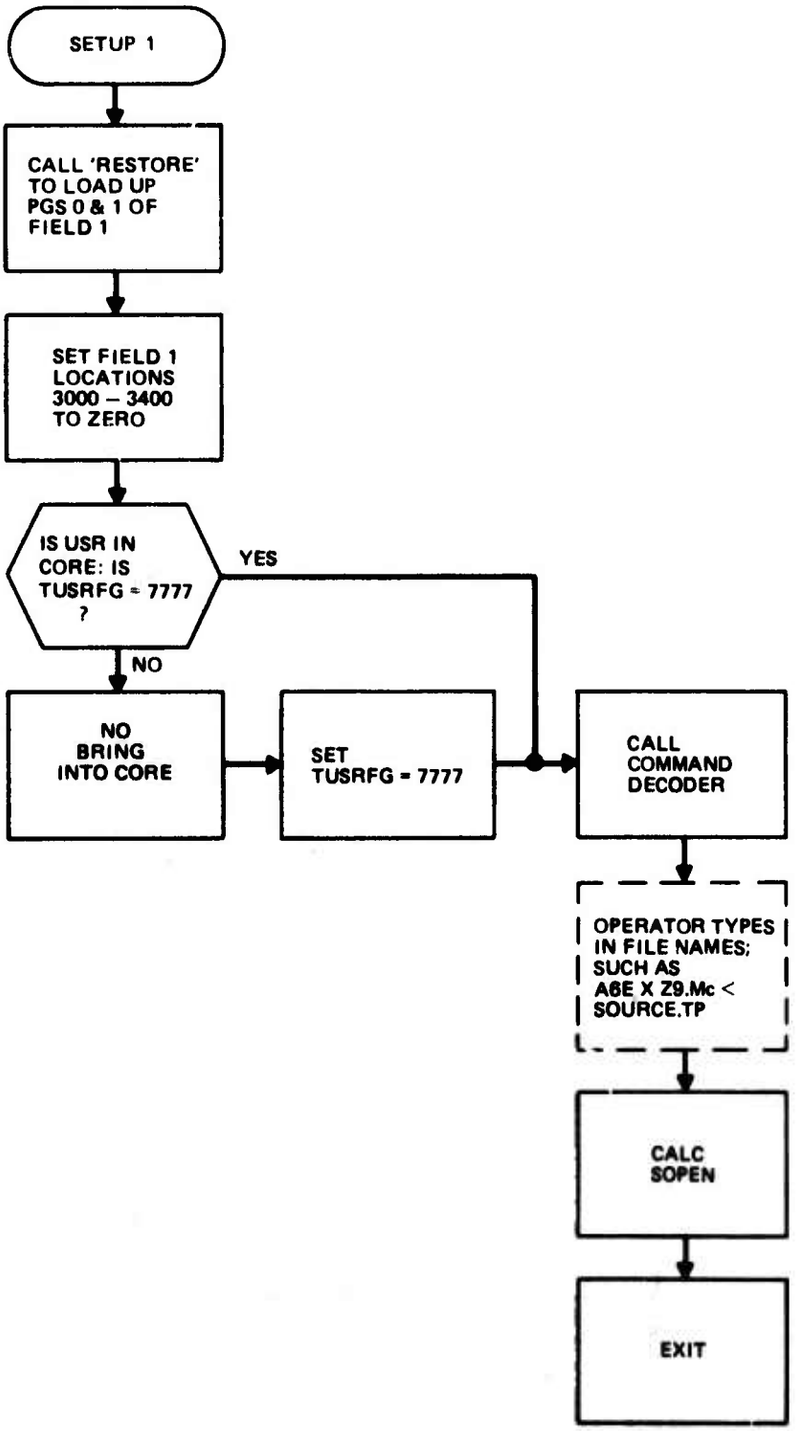


Figure 41. Dissection of Parts Programming Software – Step 2

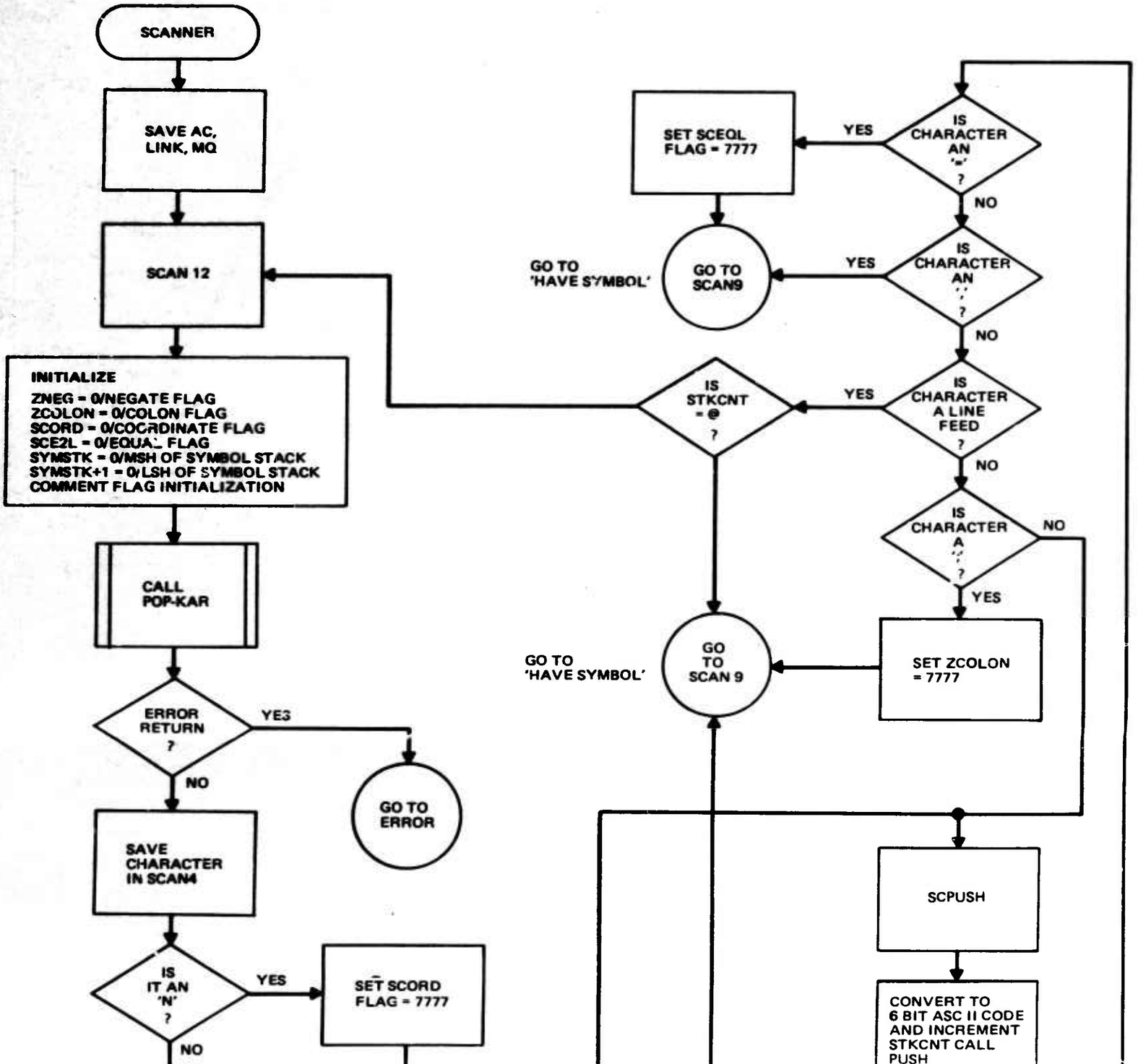

SCANNER
SAVE AC, LINK, MQ
SCAN 12
INITIALIZE
ZNEG = 0/NEGATE FLAG
ZCOLON = 0/COLON FLAG
SCORD = 0/COORDINATE FLAG
SCE2L = 0/EQUAL FLAG
SYMSTK = 0/MSH OF SYMBOL STACK
SYMSTK+1 = 0/LSH OF SYMBOL STACK
COMMENT FLAG INITIALIZATION
CALL POP-KAR
ERROR RETURN ?
YE3
NO
GO TO ERROR
SAVE CHARACTER IN SCAN4
IS IT AN 'N' ?
YES
SET SCORD FLAG = 7777
NO
SET SCEQL FLAG = 7777
YES
IS CHARACTER AN '=' ?
NO
GO TO 'HAVE SYMBOL'
GO TO SCAN9
YES
IS CHARACTER AN ':' ?
NO
IS STKCNT = @ ?
YES
IS CHARACTER A LINE FEED ?
NO
IS CHARACTER A ':' ?
NO
YES
GO TO 'HAVE SYMBOL'
GO TO SCAN 9
SET ZCOLON = 7777
SCPUSH
CONVERT TO 6 BIT ASC II CODE AND INCREMENT STKCNT CALL PUSH

Figure 42. Dissection of Parts Programming Software – Step 3 (Sheet 1 of 2)

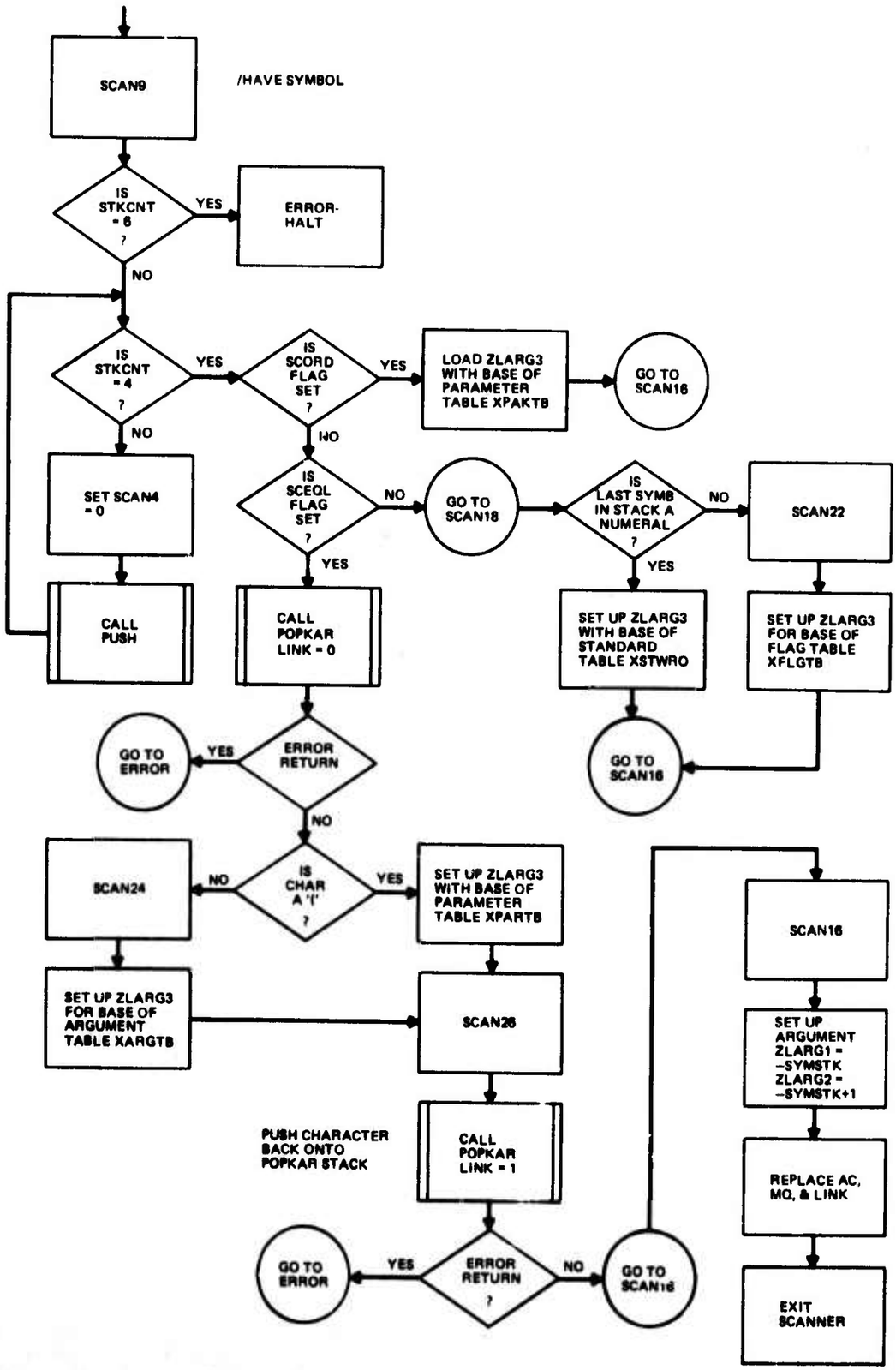


Figure 42. Dissection of Parts Programmers Software — Step 3 (Sheet 2 of 2)

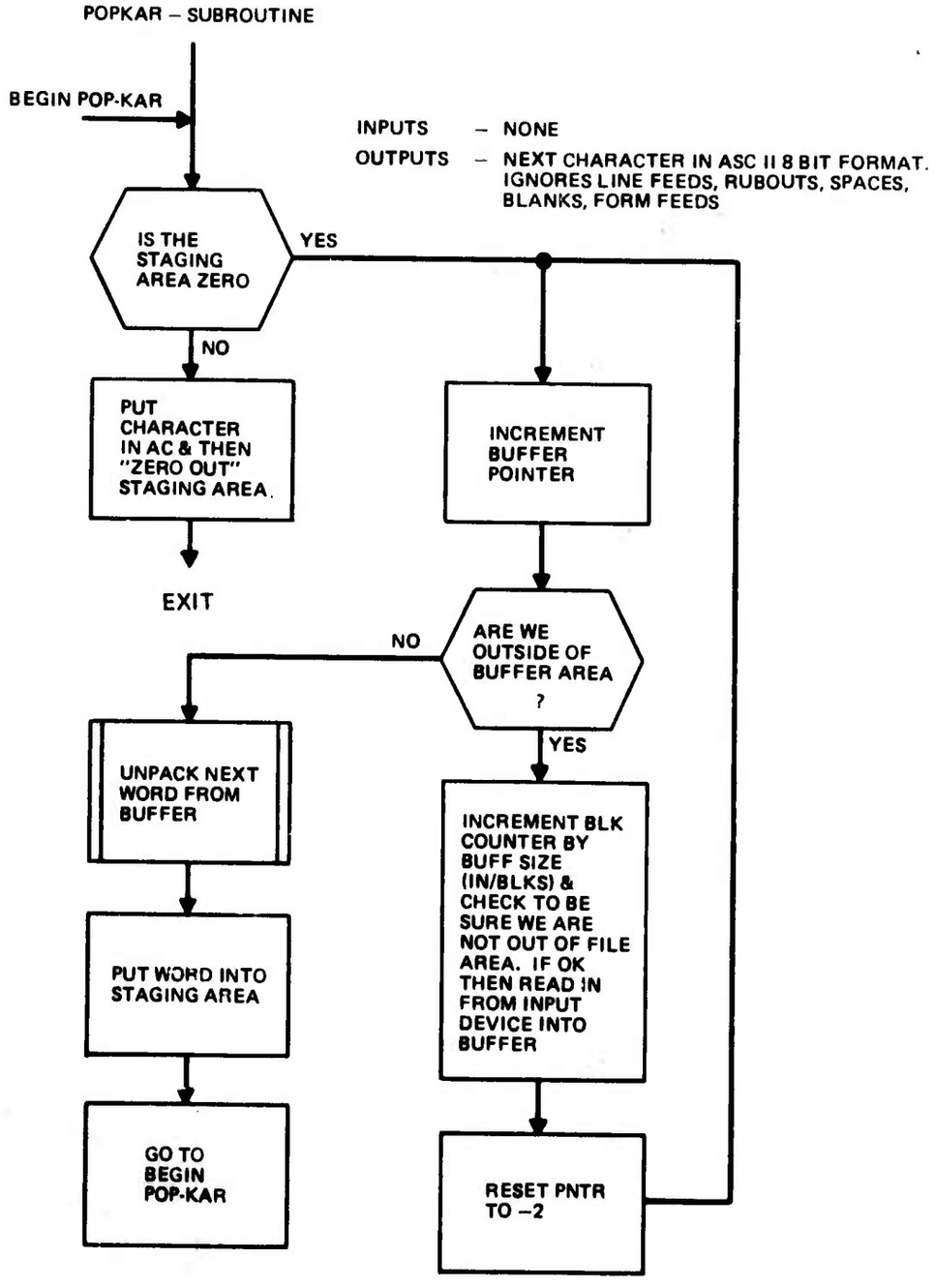


Figure 43. Dissection of Parts Programming Software – Step 4

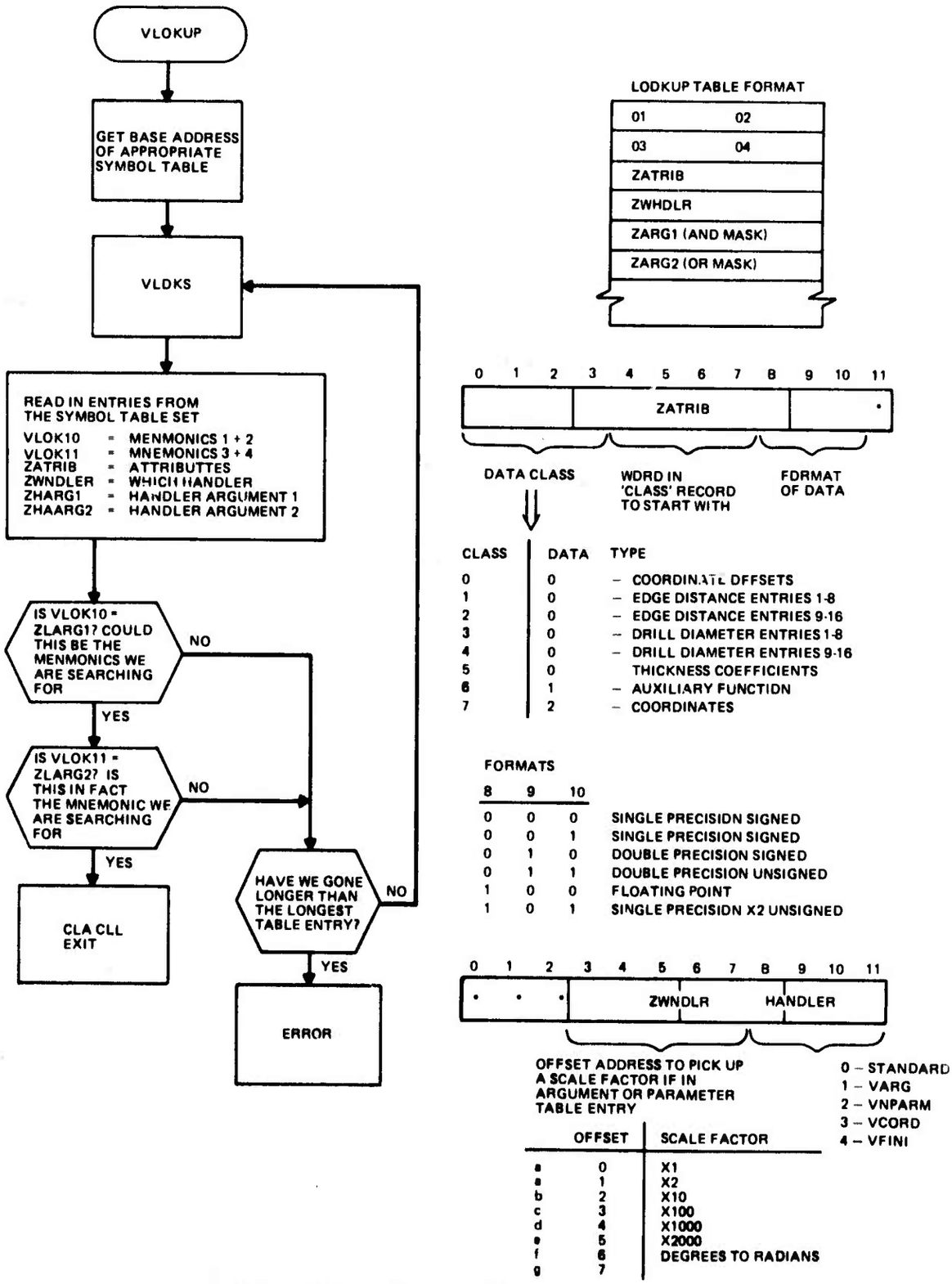


Figure 44. Dissection of Parts Programming Software – Step 5

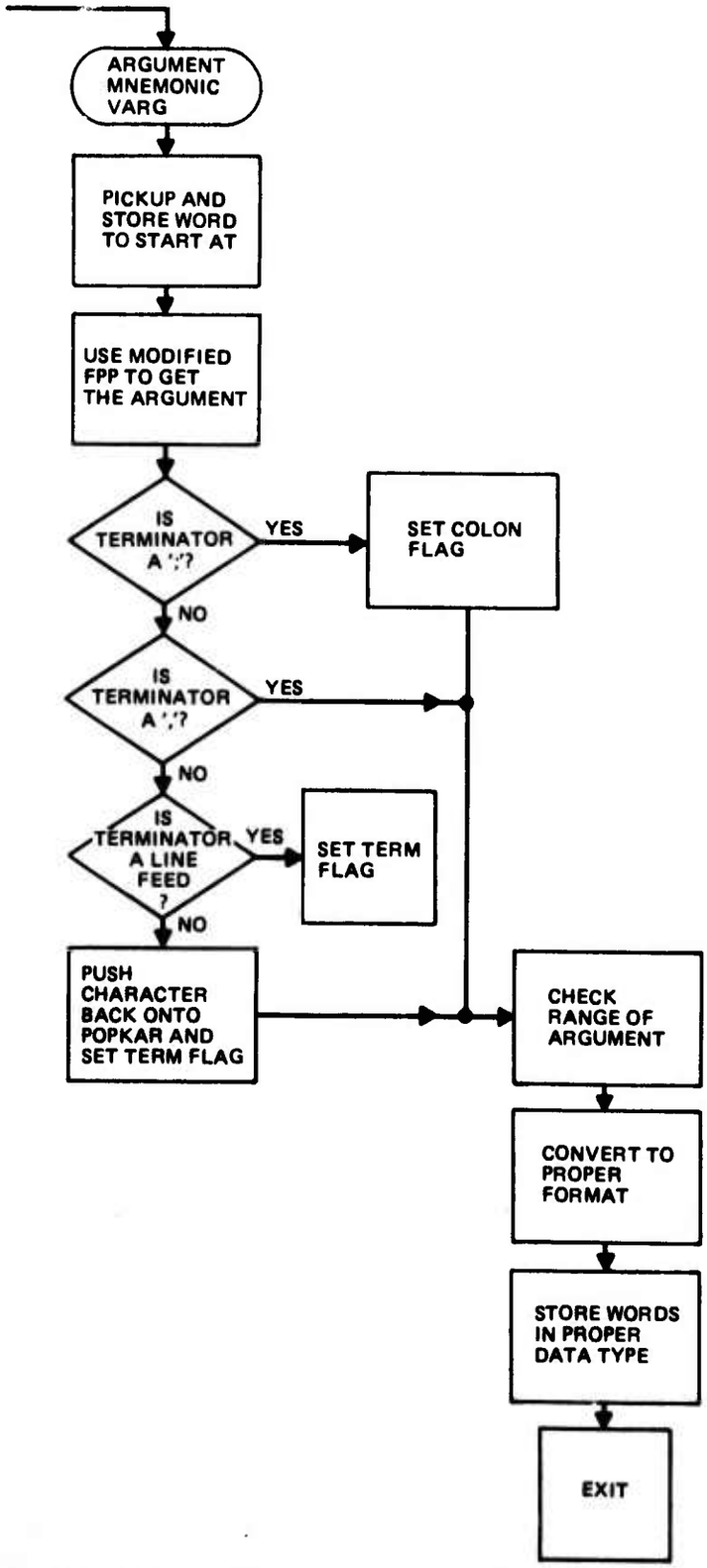


Figure 45. Dissection of Parts Programming Software – Step 6

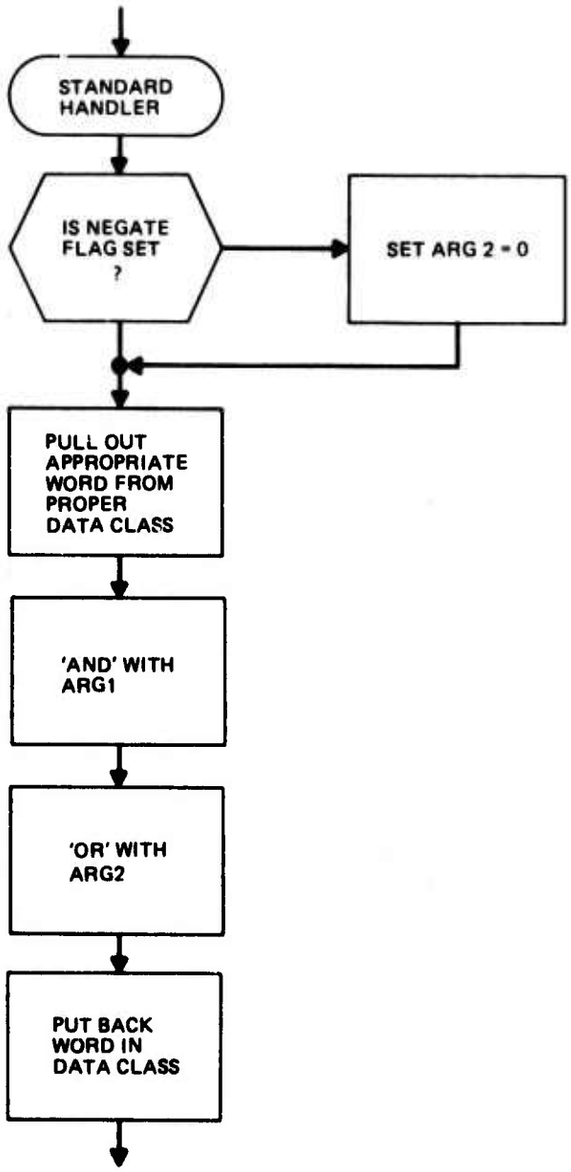


Figure 46. Dissection of Parts Programming Software – Step 7

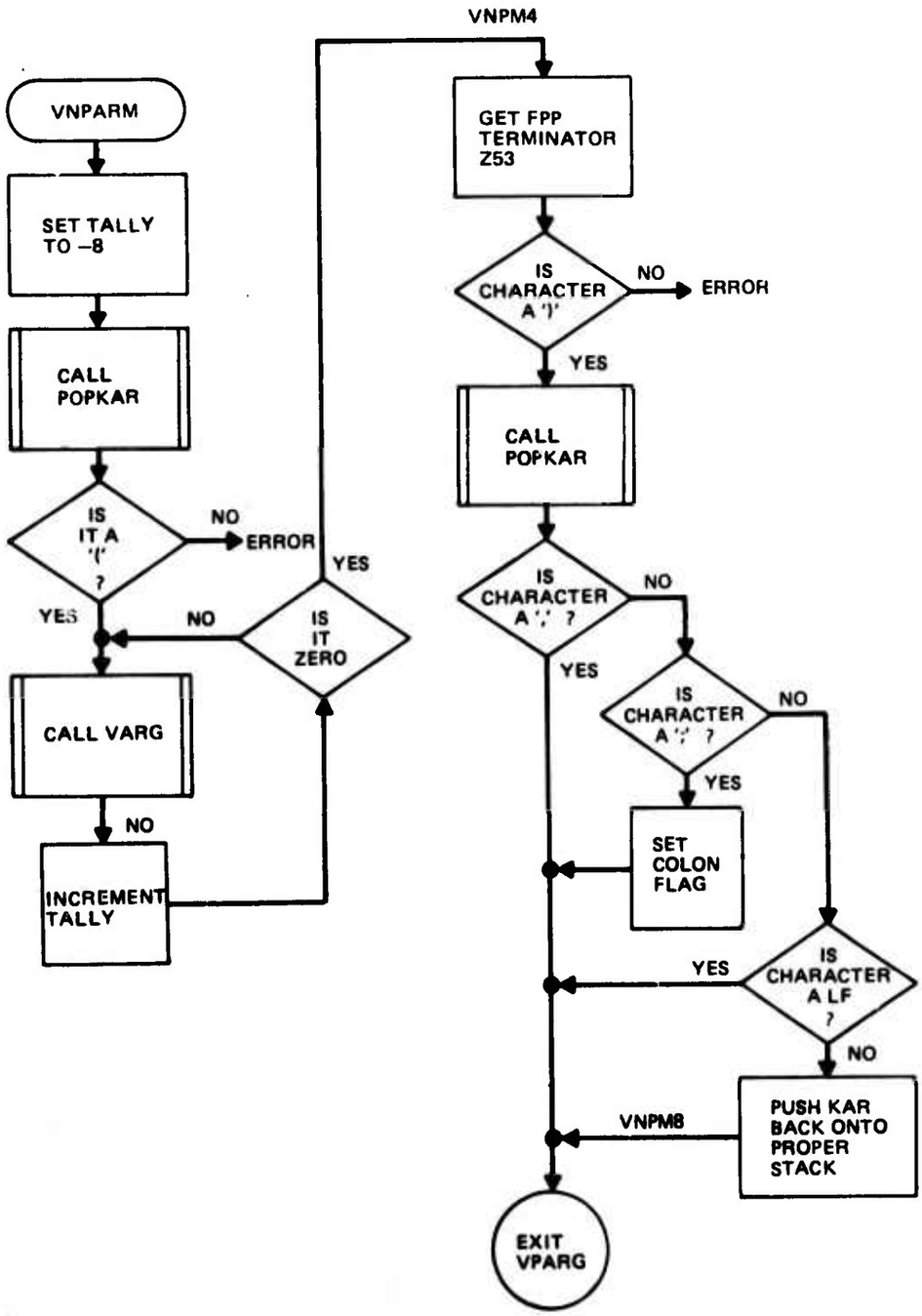


Figure 47. Dissection of Parts Programming Software – Step 8

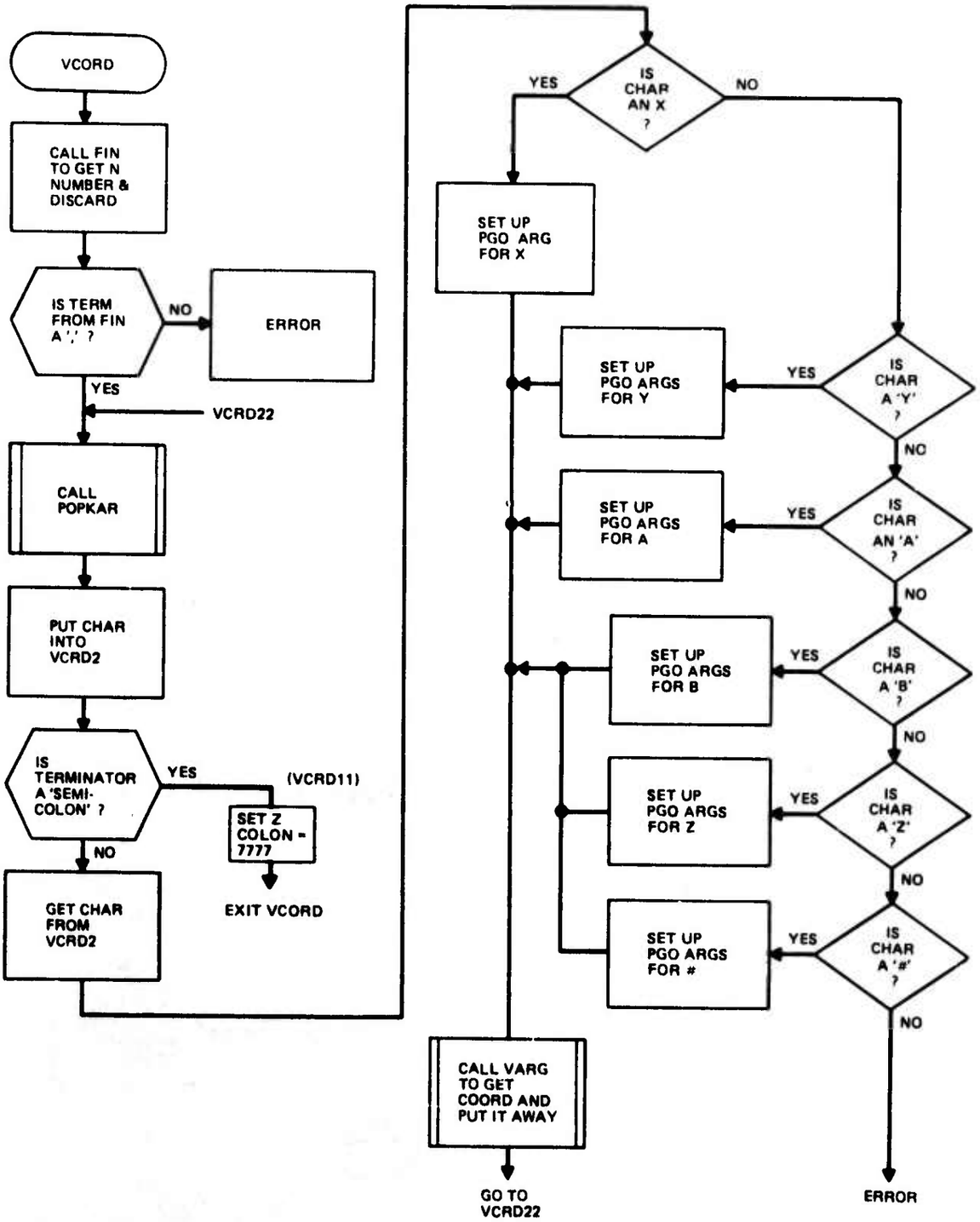


Figure 48. Dissection of Parts Programmers Software – Step 9

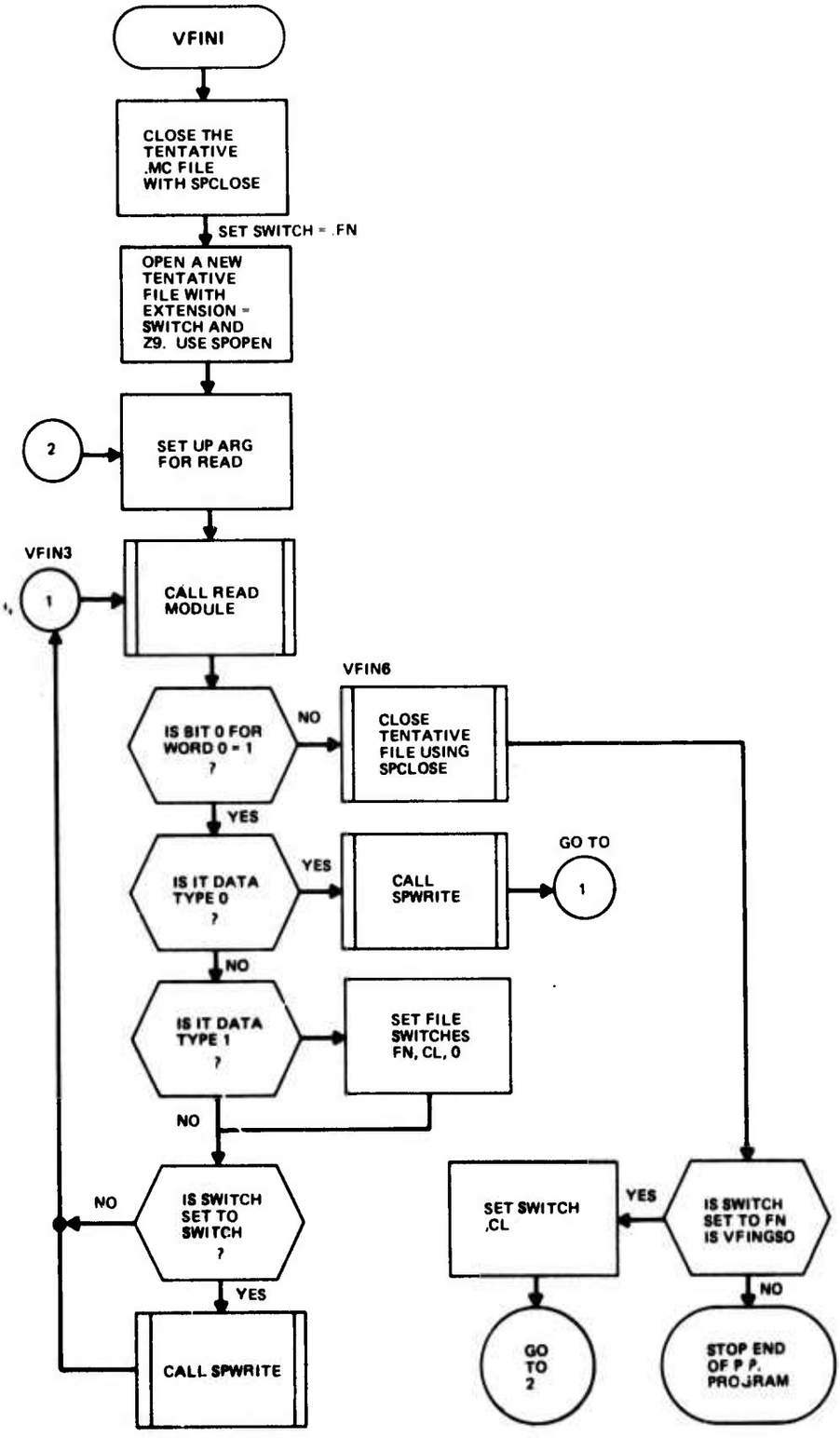


Figure 49. Dissection of Parts Programming Software – Step 10

SECTION IV

SYSTEM EVALUATION

A. INTRODUCTION

The system built under this program was evaluated for its effectiveness in meeting the stated goals. Items involved included tooling and chip clearances, rapid advance and adaptive sensing, programming and software, materials selection, coolants and lubricants, and hole quality.

B. TOOLING AND CHIP CLEARANCE

Early in the testing of the first nosepiece, it was observed that material chips were packing up in the nosepiece area causing an incorrect depth adjustment in the countersink stop position. The first nosepiece was constructed of aluminum and had openings for material chip removal. This nosepiece, which was specifically designed for the Model 31C-800C Rockwell drill gun, was subsequently modified by enlarging the chip removal cutouts to facilitate chip removal (Fig. 50). The Rockwell Model 31L-800C drill gun delivers 200 lb of thrust at 90-psig supply pressure. The Quackenbush Model QDP-15 drill gun, on the other hand, delivers about 1200 lb of thrust. The Quackenbush nosepieces were made of AISI 321 stainless steel with generous cutouts for chip removal (Fig. 51, 52 and 53). The majority of the holes, about 1200 out of 2000 drilled in the last A-6E production wing cover on the Five-Axis Assembly Fixture were mostly 0.190-in. diameter with some 5/32 and 1/8-in. diameter holes. These were finished countersunk holes done with the Rockwell tool and aluminum nosepiece. Table V shows the countersink diameters of holes drilled on the production A-6E wing and the tolerance held. The countersink diameter varied 0.009 in. which correspond to a depth variance of 0.00375 in.

The Quackenbush gun was used to drill 0.190-to 0.250-in. diameter holes because of its greater power. The countersink depth adjustment on the Quackenbush gun differs from that of the Rockwell unit. The Rockwell gun has a non-rotating cylinder which advances with the rotating spindle during drilling. This allows placement of the fluidic port on the cylinder rather than on the forward end of the nosepiece. In this position it is further away from the chips generated during drilling. The Quackenbush gun has only a rotating spindle which advances, necessitating placement of the countersink stop on the drill bit and the fluidic port on the forward end of the nosepiece (Fig. 51, 52 and 53). Figure 54 shows the assembly of the countersink stop on the drill bit. The two nuts are tightened at the proper depth adjustment required for the countersink. The forward face of the forward nut contacts the countersink surface of the nosepiece, blocking a fluidic port and terminating the drilling operation. Another nosepiece designed for production allows for external adjustment of the countersink stop on the Quackenbush nosepiece. This nosepiece also incorporates a drill bushing that restrains the drill from lateral movement to give a tighter tolerance hole. The countersink stop can be adjusted externally on the Rockwell nosepiece.

The first nosepiece fitted to the Quackenbush gun (Fig. 51) had to be strengthened because of the increased thrust of the gun. A delay was built into the fluidic sensing to obtain a dwell on the countersink surface. When the Quackenbush gun reaches the countersink stop,

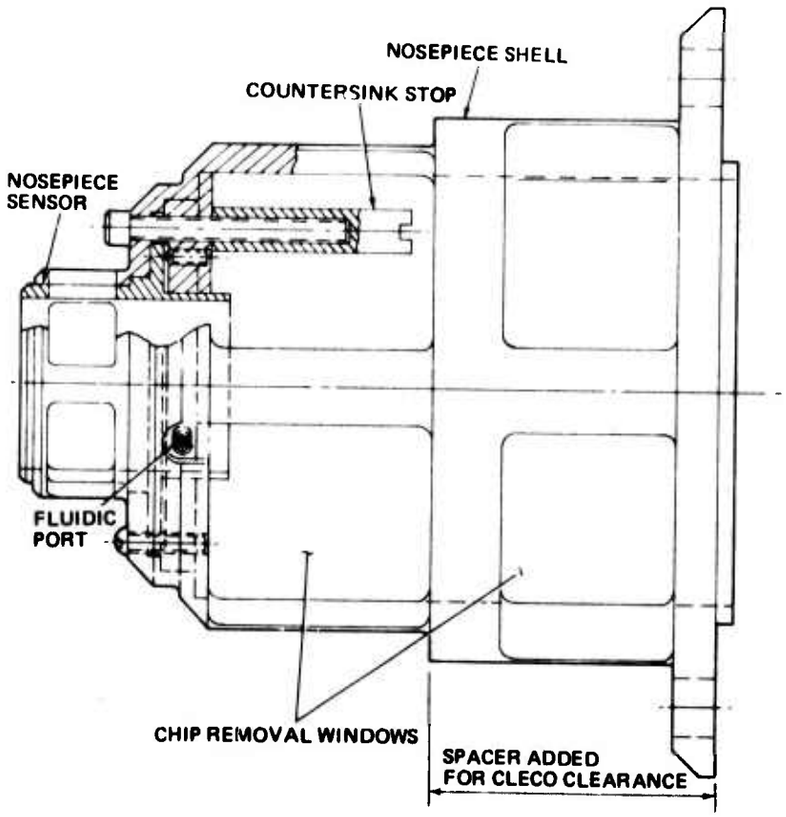


Figure 50. Rockwell Nosepiece

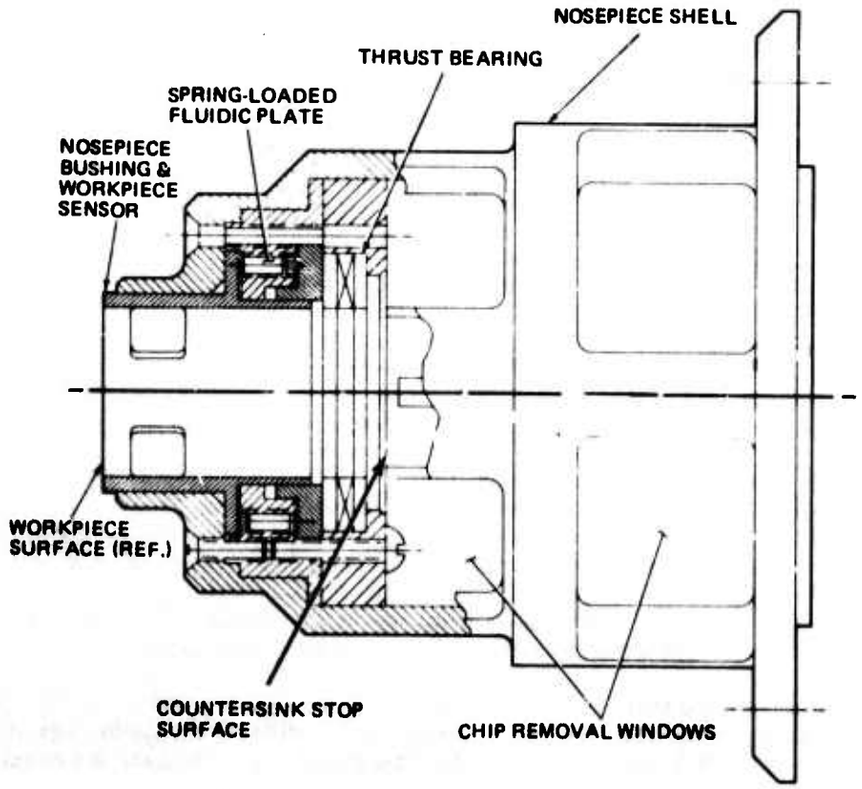


Figure 51. Altered Nosepiece for Quackenbush Gun

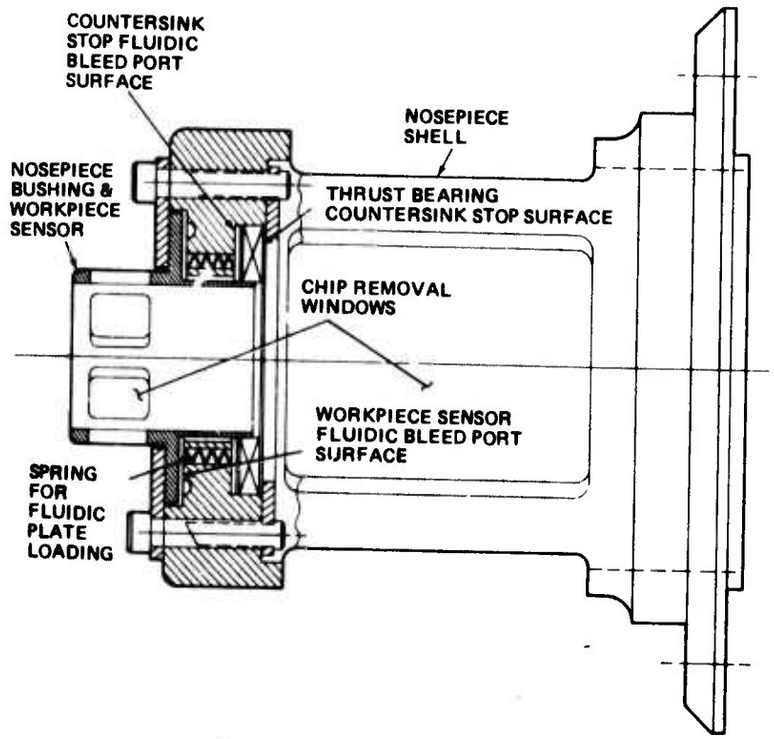


Figure 52. One-Piece Quackenbush Nosepiece

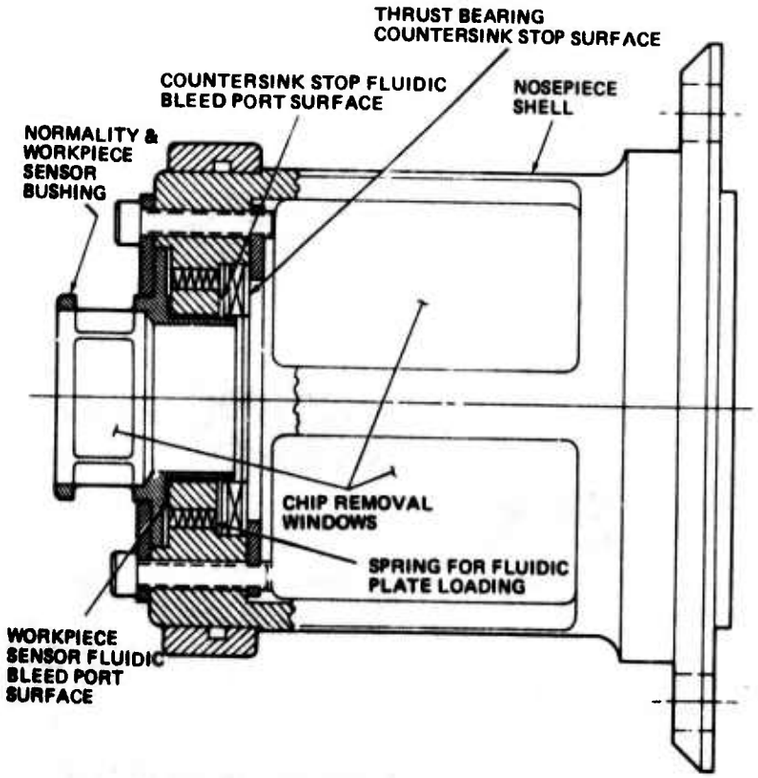


Figure 53. Quackenbush Nosepiece with Normality Sensor

Table 5. Sample Set of Countersunk Holes on Production Wing

HOLE NO.	CSK. DIA., IN.	HOLE NO.	CSK. DIA., IN.	HOLE NO.	CSK. DIA., IN.	HOLE NO.	CSK. DIA., IN.
1414	.340	1423	.341	1399	.340	1439	.335
1415	.340	1406	.341	1432	.337	1390	.341
1413	.340	1424	.339	1433	.337	1440	.336
1416	.340	1405	.340	1398	.340	1389	.340
1412	.340	1425	.340	1434	.337	1441	.335
1417	.340	1404	.343	1397	.340	1488	.335
1411	.339	1426	.340	1435	.338	1487	.340
1418	.338	1403	.342	1396	.340	1442	.340
1410	.340	1427	.340	1436	.338	1386	.340
1419	.340	1428	.340	1395	.338	1443	.335
1409	.341	1402	.339	1394	.340	1385	.340
1420	.340	1429	.338	1437	.337	1444	.338
1421	.340	1401	.334	1393	.337	1384	.340
1408	.341	1430	.338	1392	.340	1445	.338
1422	.338	1400	.337	1438	.335	1383	.340
1407	.342	1431	.337	1391	.342	1446	.340

Notes:

(1) Countersink diameters were measured by Trulock 100° Countersink Gage, No. 100-1 made by the Trio Product Company.

(2) The countersunk holes were set to be drilled to a nominal 0.340-in. countersink diameter. The hardware used to fill the countersink must end up flush with the wing skin to 0.010 in. under. This corresponds to a countersink diameter tolerance of 0.328 to 0.352 in.

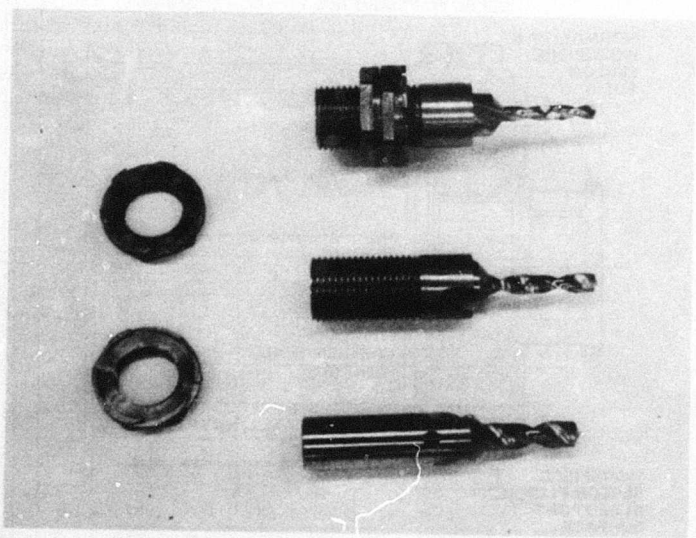


Figure 54. Drills with Adjustable Countersink Stops

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it is held there fluidically for a fraction of a second. A roll-over clutch is built into the Quackenbush gun that maintains thrust as the drill rotates in place. The second Quackenbush nosepiece (Fig. 52) was made in one piece (the first two [illegible] made in two main sections). The aft 1-3/8-in. long section was added to th[illegible] nosepieces to afford clearance for the annular cylinder from the Cleco buttons [illegible]e wing skin in position during drilling (Fig. 50).

The second Quackenbush nosepiece incorporated the initial normality sensor which was made part of the annular cylinder advance fluidic stop. Because of difficulties encountered in fabrication, the nosepiece functioned correctly but the normality sensor did not operate.

The third Quackenbush nosepiece (Fig. 53) incorporated an improved method for assembling the normality sensor as part of the nosepiece. This nosepiece was installed and tested by varying the alpha and beta angles from true normal. In a normal drill sequence, the annular cylinder advances and, upon contact with the material, the nosepiece fluidically signals the drill to start. This nosepiece was designed not to give the fluidic start signal if the drill axis is off normal by a certain amount. This prevents blocking of the fluidic port. Table 6 shows the angles from true normal at which the drill will or will not start. The range in which the drill will not start varies from 1/2 to 1.4 degrees for the different axes. For drilling of wing covers, a maximum of two degrees from true normal is acceptable. The tolerance from true normal of the normality sensor, however, can be tightened depending on the machining tolerances of the material or the design requirements of the structure.

C. RAPID ADVANCE AND ADAPTIVE SENSING

In a normal drill/countersink operation the entire sequence of drill approach, drilling of the material, passage of the drill through the hole, and countersinking of the hole is done at the optimum feed for machining the material. This results in time lost "drilling air" during drill approach and passage of the drill shank through the hole. Although the drill length can be optimized to reduce this loss, the drill must be long enough to penetrate the thickest cross-section of material with some additional length required for resharpening of the drill.

Table 6. Testing of Fluidic Normality Sensor

ALPHA AXIS (ALPHA ANGLE = 190.85 STEPS/DEG)			
STEPS	**+ ALPHA**	**-ALPHA**	**ANGLE, DEG**
0 – 75	START	START	0 –0.4
75 – 100	•	START	0.4 –0.5
100 – 175	NO START	•	0.75–0.92
175 – 200	NO START	NO START	0.92–1.05
BETA AXIS (BETA ANGLE 183.88 STEPS/DEG)			
STEPS	**+ BETA**	**-BETA**	**ANGLE,DEG**
0–75	START	START	0 –0.4
75–125	•	START	0.4 –0.66
125–175	NO START	START	0.66–0.95
175–225	NO START	•	0.95–1.2
225–250	NO START	NO START	1.2 –1.37

START – Indicates annular cylinder stopped at material and drilling proceeded normally.
NO START – Indicates annular cylinder stopped at material and drill gun did not start
• – Indicates tolerance band. Drill started at times and at other times it did not.

Applying the thermoelectric principle of dissimilar metals to adaptive sensing, as shown in Fig. 55, the time used "drilling air" can be cut down significantly. When the drill cuts aluminum or titanium, a measurable voltage can be taken off the drill spindle because the bearings act as insulators. This voltage is amplified and used to close the rapid-feed-bypass-control solenoid, forcing the drill motor to feed at the preset feed for the subject material. As the drill breaks through the material, the thermoelectric signal drops off and the bypass solenoid is energized. This allows the drill motor to advance rapidly until the countersink contacts the work, generating the thermoelectric signal which again closes the rapid-feed solenoid valve.

To enable evaluation of the cost impact of using adaptive sensing as a means of controlling rapid advance, the Rockwell drill motor (No. 31L-800C) was evaluated for adaptive sensing modification. A bypass could be installed around the feed-rate flow-control orifice by using an existing port and machining an additional port upstream of the orifice. A solenoid valve in the bypass would allowselection of either high-feed advance (valve open) or a predetermined feed rate (valve closed). The thermoelectrical signal pickup would be placed to pick up the signal directly from the drill shank. The pickup would be shielded from chips by the countersink fluidic sensor housing in the back end of the nose-piece.

In the drilling of a wing skin, drill lengths can be optimized so that very little time is wasted "drilling air". For example, a 0.375-in. stackup of aluminum can be drilled with a 0.500-in. long drill, which allows for less than 0.125 in. "drilling air" before the countersink engages the material. Use of a 0.190-in. diameter drill at 3000 rpm and 0.004 in. per revolution would consume just under 4 sec/hole. This drill could not be resharpened, however, and its special length would necessarily result in a high tool cost per finished structure. A standard 0.90-in. long, 0.190-in. diameter drill for the above example would take just under 6 sec/hole.

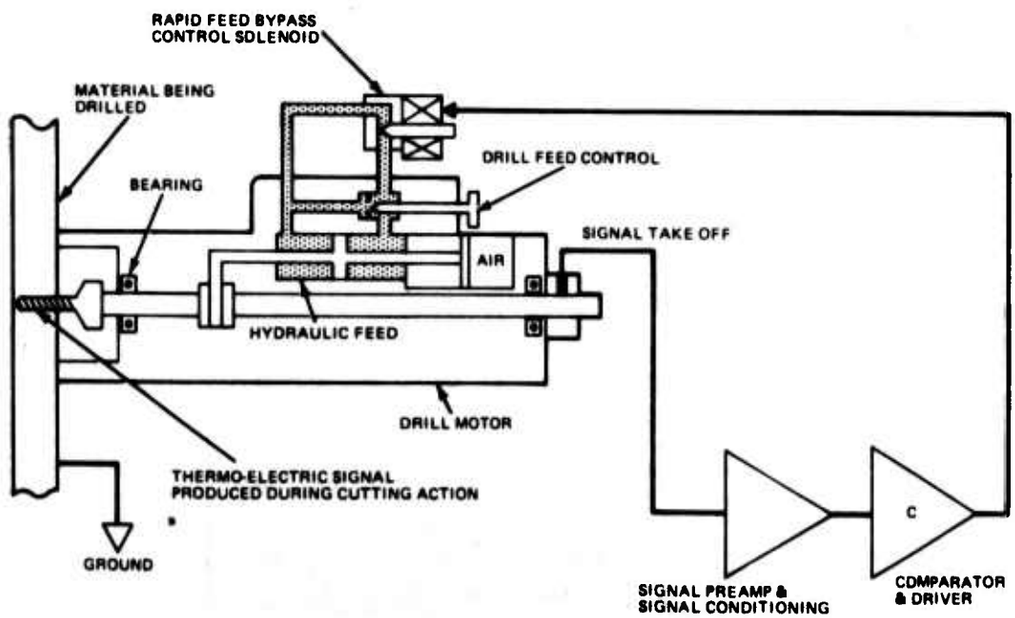


Figure 55. Rapid Advance and Adaptive Sensing Schematic

Applying adaptive sensing to the above example, a standard drill/countersink could be used in combination with adaptive control, resulting in a drilling time of just under 3.6 sec/hole. As can be seen, adaptive sensing can reduce drilling time by about 25% while using standard resharpenable tools rather than especially shortened drills. In addition, since most wing structures incorporate a tapering skin cross-section thickness, adaptive sensing automatically compensates for the thinner sections and results in additional time savings.

Application of adaptive sensing to drilling of titanium reduces total drilling time even more dramatically. The Mechanized Track Drilling Fixture (Fig. 56), which was modified for adaptive sensing, is being used to drill F-14 front and rear beams to the top and bottom wing covers. Approximately 1800 0.190-in. drill/countersink holes are machined per left or right wing with a stackup varying from 0.188 to over 0.400 in. A 450-rpm, HS-1 Omark Spacematic drill is used at a feed of 0.004 in/revolution. Figure 57 shows the Spacematic drill converted for adaptive drilling. Without adaptive sensing, the drill/countersink operation alone takes about 24 sec. With adaptive sensing, the operation requires about 15 sec/hole. This results in a savings of 9.1 hr/wing. No significant change in tool wear was noted. A heavier duty Rockwell drill gun can be similarly installed in the drill head assembly of the Automated Assembly Fixture for drilling titanium. Model A of Rockwell drill gun No. 46LD802 fits the drill head and provides one horsepower and 440 lb of thrust. This gun can be modified for adaptive sensing in the same manner as that described for the Rockwell No. 31L-800C drill gun. The drill gun, modified for adaptive drilling, can be used to machine titanium structures with resharpenable tool bits at a 25 to 40% savings in drilling time.

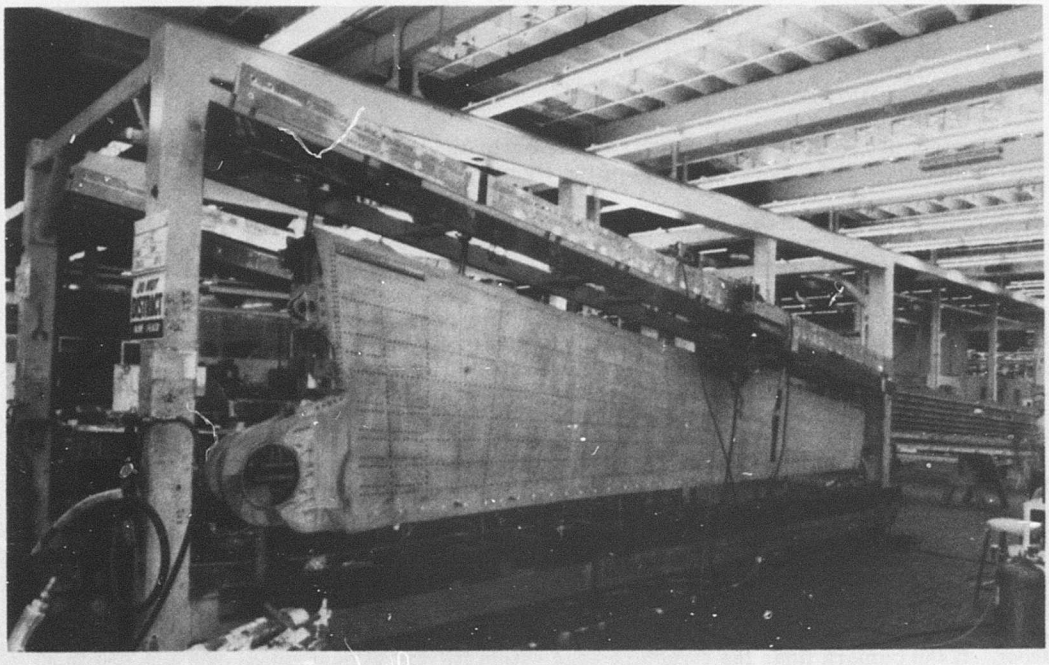


Figure 56. Mechanized Track Drilling Fixture

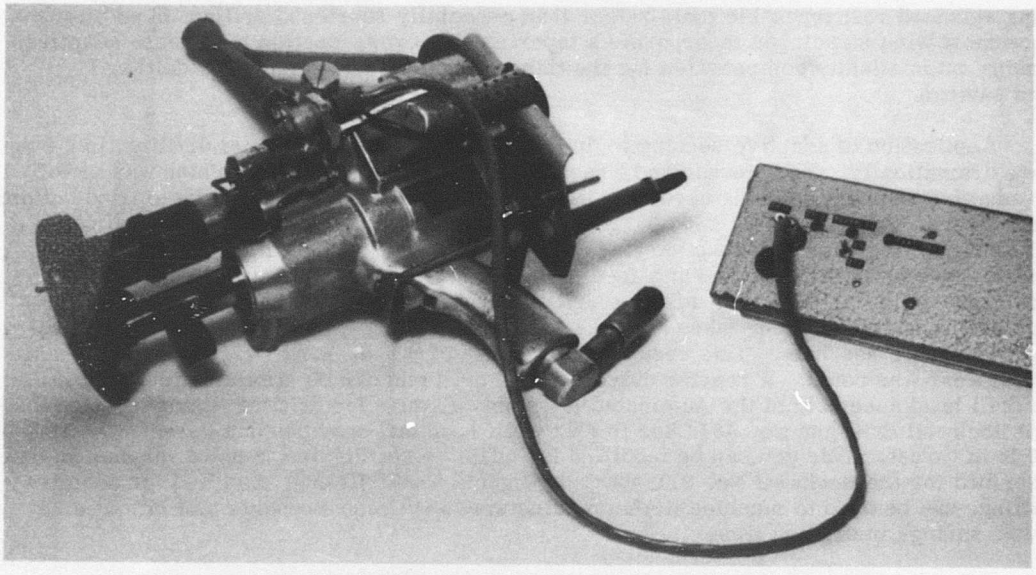


Figure 57. Omark Spacematic Drill Converted for Adaptive Drilling

D. PROGRAMMING AND SOFTWARE

System programming and software were evaluated by conducting various tests to determine the accuracy and reliability of the control system.

1. Scan Camera Operation

As discussed in Subsection III D, the camera-generated data are of prime importance to the system. Placement and operation of the scan camera, therefore, were tested for accuracy. Camera focal length was first checked for proper setting. With the focal length set at its closest position (under 4 ft), the unit accurately measured a 0.096-in. diameter rod at a distance of 3-1/2 in. from the camera lens. The camera and drill unit axes are aligned, because the housings of both units are firmly and accurately attached, in turn, to the spherical bearing in the annular cylinder.

Camera measurements were verified against commanded drill head movements on the Y-axis. Display readings of the Y-axis versus the Reticon camera controller were recorded by setting the camera midpoint reading (256) to a stringer edge and varying the Y-axis displacement 0.150 in. on either side. Figure 58 compares the camera and display readings to a straight-line function. At a display reading of 250 (camera reading of 359), a disparity of 0.006 in. occurs. If in seeking the edge of the stringer, however, the camera is more than 0.050 in. from the center (256), the computer run-time software drives the camera to its computed midpoint and rescans the hole after taking into account any over or under-shoot. If the camera finds the structure edge within its operational range (256 ± 0.050 in.), it is not moved. Hole position is calculated by the computer based on the camera reading once the reading is within ± 0.050 in.

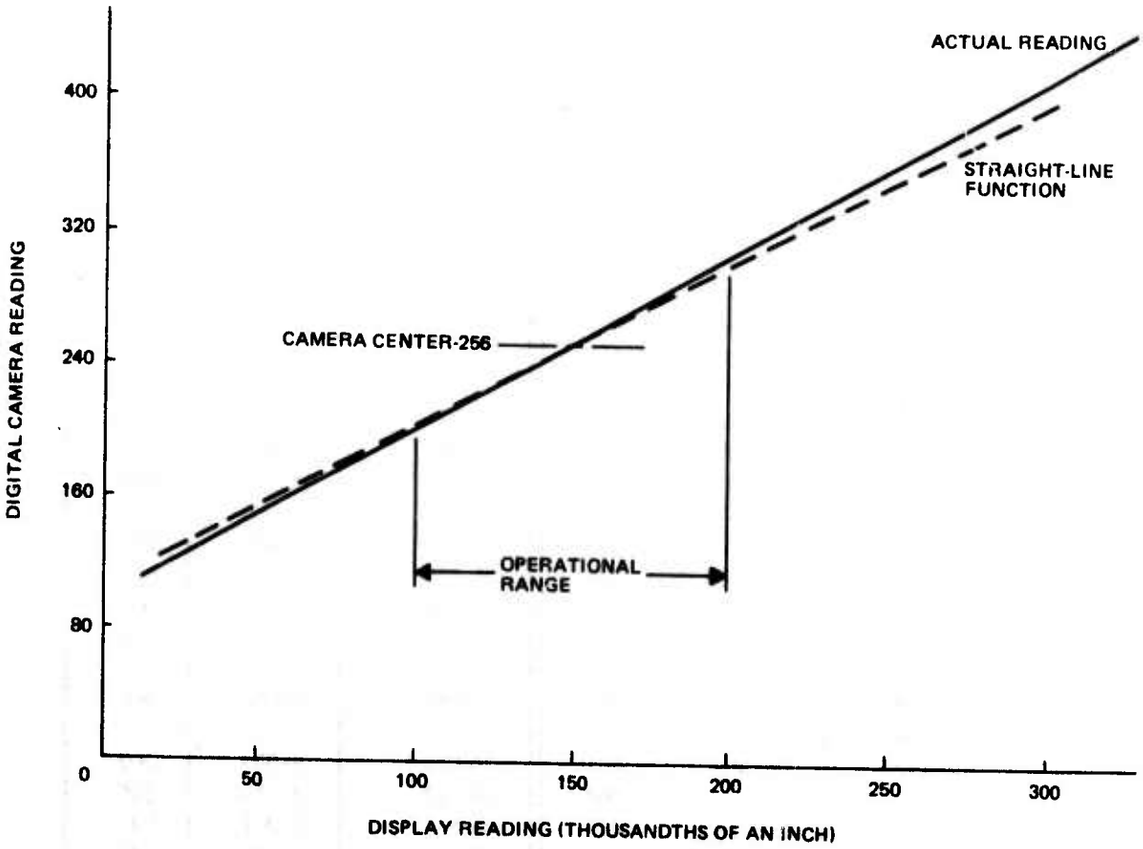


Figure 58. Camera vs Display Readings

In the actual automated fixture, a programmed deadband of ± 0.007 in. is allowed on X- and Y-axis movements to prevent the drill head assembly from oscillating, while holding it to an acceptable positional tolerance. The oscillation would occur because of overshoot and the resultant effort to reach the exact dimension called for.

2. Actual Versus Targeted Coordinates Comparison

The first step in the procedure for using the Automated Assembly Drilling Fixture is to scan the understructure with the digital scanning camera looking at the edge of the stringer or rib. The data from the camera are then used to correct the nominal drill coordinates (known as the master coordinate map). The corrected coordinates are then stored by the computer to be used for the drilling operation. The first set of holes drilled is the "Cleco run". This is a set of approximately 240 (in the case of the A-6E) holes drilled and fitted with pressure buttons to hold the wing skin securely to the substructure while the regular fastener holes are drilled. Table 7 shows a sample of 30 Cleco holes drilled on a production wing. The corrected X- and Y-target coordinates were printed-out by the computer. During the drill run, as each hole was drilled, displacement of the X and Y coordinates from the actual position displays was recorded. The differences between the targeted and actual coordinates are also shown in Table 7. The standard deviation of the X and Y coordinates was 0.0039 and 0.0034 in. respectively. This is well within the hole tolerance and the programmed deadband of ± 0.007 in.

Table 7. "Cleco Run" for Production Wing (Inches)

HOLE NO.	TARGETED X COORD	ACTUAL X COORD	DELTA	TARGETED Y COORD	ACTUAL Y COORD	DELTA
10	79.164	79.165	.001	10.962	10.964	.002
11	80.277	80.273	−.004	11.022	11.023	.001
12	108.340	108.336	−.004	12.552	12.553	.001
13	109.732	109.734	.002	12.628	12.630	.002
14	111.026	111.022	− 004	12.692	12.692	0
15	130.384	130.380	−.004	13.821	13.822	.001
16	130.384	130.380	−.004	13.821	13.822	.001
17	133.153	133.146	−.007	13.972	13.976	.005
18	163.209	163.208	−.001	15.559	15.563	.004
19	163.937	163.934	−.003	15.596	15.601	.005
20	164.648	164.641	−.007	15.638	15.644	.006
21	168.529	168.526	−.003	14.465	14.467	.002
22	168.142	168.135	−.007	13.503	13.503	0
23	CONTROL	MOVE				
24	168.886	168.892	.006	20.554	20.560	.006
25	CONTROL	MOVE				
26	158.592	158.591	−.001	20.070	20.073	.003
27	159.876	159.872	−.004	20.119	20.125	.006
28	157.183	157.184	.001	20.011	20.014	.003
29	158.670	158.674	.004	19.165	19.168	.003
30	158.445	158.443	−.002	18.988	18.991	.003
31	CONTROL	MOVE				
32	146.896	146.891	−.005	19.592	19.595	.003
33	145.408	145.406	.002	19.532	19.535	.003
34	147.356	147.352	−.004	18.577	18.580	.003
35	145.951	145.950	−.001	18.505	18.508	.003
36	CONTROL	MOVE				
37	133.374	133.371	−.003	19.73	19.075	.002
38	134.821	134.824	.003	19.132	19.137	.005
39	131.905	131.905	0	19.013	19.015	.002
40	133.851	133.854	.003	18.063	18.065	.002
41	132.249	132.245	−.002	17.990	17.994	.004
42	CONTROL	MOVE				
43	118.704	118.706	.002	18.477	18.480	.003
44	119.630	119.630	0	17.491	17.494	.003
45	117.769	117.764	−.005	17.416	17.420	.004

3. Alpha and Beta Drives Accuracy

The Alpha and Beta drives are accomplished with ball screws driven with stepper motors mounted on the back of the drill assembly. Relatively inexpensive ball screws are used instead of more costly precision drive screws since the distance of the drive screws from the drill point is 7.5 times the distance of the drill point to the pivot point. This means that an error at the output of the angular drive system will be reduced by a factor of 6.5 at the drill tip (Fig. 59). If the maximum tolerance of the ball screw (0.0015 in./in.) was used on a full 9-degree-from-center angular change, it would only produce a 0.001-in. error at the drill tip.

The Alpha and Beta stepper motors are driven at 250 to 300 steps/sec, while the X and Y motors are driven 2000 steps/sec (maximum). This is done because of the small distance that has to be traversed for angular changes and the ample time available for these changes during the X and Y travel between holes. The small mass of the angular drives and the small angular change from one hole to the next allows the motors to react very quickly to computer commands. A maximum two-step error at the motor has been experienced, which translates to less than 0.001 in. error at the drill tip.

4. Z-Axis Motion-Operation and Focal Tolerance

Z-axis motion, perpendicular to the X and Y planes of motion, is provided by the pneumatic annular cylinder. For the drilling operation, the computer activates a solenoid valve pressurizing the cylinder forward. Stopping of the cylinder at the workpiece, drilling, countersinking, and cylinder reaction is performed by fluidic control. At completion of the countersinking operation, a signal is sent to the computer which either allows full cylinder retraction for obstruction bypass or halts the cylinder at partial retraction by activating a Block solenoid. The Block solenoid activates the Bellows hydrocheck which hydraulically locks the annual cylinder in position (Fig. 60). This routine saves time by not allowing the annular cylinder to fully retract and advance for each hole drilled. For scanning camera operation, annular cylinder movement is handled completely by the computer. In this operation the computer signals the Start, Block, or Retract solenoid valves to position the annular cylinder. Z-axis or annular cylinder position data are supplied by a linear potentiometer attached to the cylinder (Fig. 60). The computer compares annular cylinder position from the potentiometer output to the programmed position and initiates a start or retract movement. As the potentiometer output becomes equal to the programmed input the computer signals the Block valve, stopping the annular cylinder. This occurs within a 0.040-in. tolerance which falls within the focal length tolerance of the scanning camera.

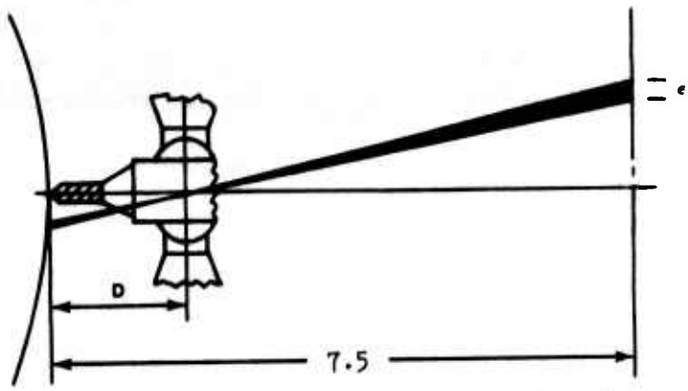


Figure 59. Minimized Impact of Angular Drive Output Error on X and Y Positions

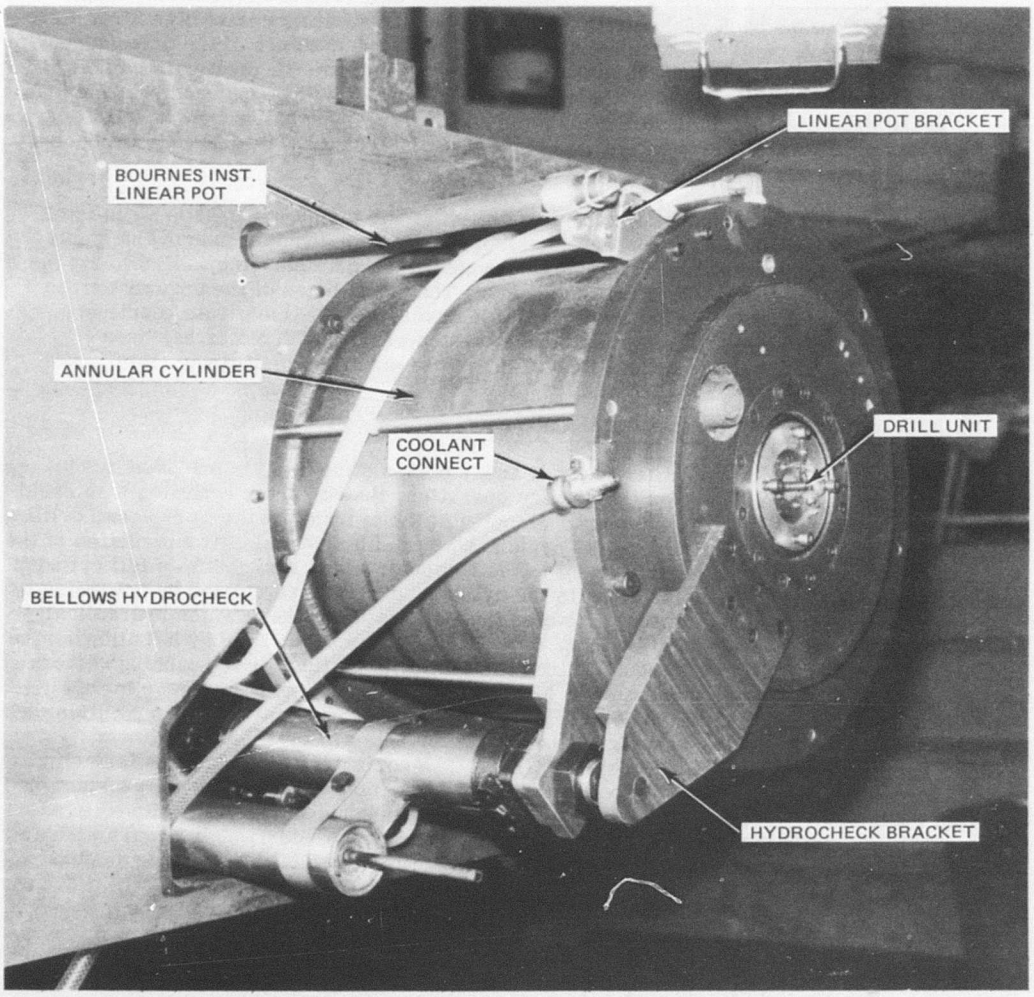


Figure 60. Z-Axis Drive System

5. Tolerance Summary

If the maximum tolerances were taken in one direction and added to each other, that is, 0.007-in. deadband on X and Y travel, 0.005-in. camera vs actual reading at the higher operational range, 0.001-in. ball screw tolerance, and under 0.001-in. angular stepper motor overshoot, the total would still be under 0.014 in. Z-axis motion does not add to positional tolerance. Although the maximum tolerance will rarely occur in one direction, automated drilling still falls within a true position hole tolerance of ± 1/64 in. If required, automated drilling tolerance can be improved by narrowing the deadband and the operational range of the scanning camera.

E. MATERIAL SELECTION

Three materials (2024-T3 aluminum alloy, Ti-6Al-6V-2Sn titanium alloy, and Hercules 3501/A-S graphite/epoxy composite) were selected for drilling tests on the Automated Assembly Fixture. These materials are typically used in aircraft wing structures. About half the titanium used in the F-14A Tomcat is the Ti-6Al-6V-2Sn alloy, which has a slightly higher ultimate strength than the Ti-6Al-4V alloy and an equivalent machinability index. The results of drilling tests performed with drills having diameters up to 1/4-in. are summarized in Table 8; results for 5/16-in. diameter drills are discussed in Subsection G.

F. COOLANTS AND LUBRICANTS

A coolant tank subassembly was mounted on the drill head assembly (Fig. 61). This installation was designed to be quickly and easily replaceable should a different coolant be required. A shutoff valve in the tank feed system is electrically activated. Once the tank is pressurized and the desired coolant flow set, the coolant will flow when the drilling action is initiated. Coolant flow is stopped when countersinking is finished. The on and off signals are controlled fluidically (Fig. 12). The coolant is routed to the nosepiece where the flow is directed at the drill. A nosepiece with the coolant hose quick-disconnect assembly installed is shown in Fig. 62 (bottom-center).

Table 8 shows the coolants and lubricants used in the drilling tests. The 2024-T3 aluminum alloy was drilled with HE-2 and Freon TB-1 coolants. Results were compared to those for dry drilling. Hangsterfer Laboratories' water-soluble oil No. HE-2 was substituted for Crystal Cut coolant because the chlorine content gave it a higher lubricity factor. Freon TB-1, a volatile fluid composed of Freon TF and 1.4 wt %/butyl-cellosolve, was used on both aluminum and titanium. Isopar M, a mineral oil with 1% butycellosolve, was also used to drill titanium. In previous tests, Isopar M was found to be as effective as Freon TB-1 for drilling titanium at one-tenth the cost of Freon. Water was used to drill the graphite/epoxy laminate.

G. HOLE QUALITY

1. Drilling Tests

Using the Automated Assembly Drilling Fixture, holes were drilled in six test plates (three 2024-T3 aluminum alloy plates, two Ti-6Al-6V-2Sn titanium alloy plates, and one graphite/epoxy plate). Sets of 20 holes were drilled in each plate using the parameters shown in Table 8. Hole diameters were measured with a Diatest small-bore gauge whigh is accurate to four significant figures. Results of the drilling tests are summarized in Table 8. Analysis of the average hole diameters and hole diameter ranges shows that the

Table 8. Summary of Drilling Test Results

TEST NO.	DRILL TYPE	DRILL SIZE	SPEED/ RPM	GUN TYPE	FEED IN/REV	MATERIAL	COOLANT	AVERAGE DRILLED HOLE DIA IN.	HOLE DIA RANGE, IN.
1	*HSS #1	.2485	2750	QUACK	.004	2024-T3	FREON	.2500	.0020
2	HSS #1	.2485	2750	QUACK	.004	2024-T3	HE-2	.2496	.0018
3	HSS #1	.2485	2750	QUACK	.004	2024-T3	DRY	.2510	.0015
4	HSS #1	.2485	3000	ROCK	.006	2024-T3	DRY	.2500	.0011
5	HSS #1	.2485	3000	ROCK	.006	2024-T3	FREON	.2494	.0003
6	HSS #1	.2485	3000	ROCK	.006	2024-T3	HE-2	.2490	.0006
7	HSS #2	.194	3000	ROCK	.006	2024-T3	HE-2	.1959	.0013
8	HSS #2	.194	3000	ROCK	.006	2024-T3	FREON	.1950	.0014
9	HSS #2	.194	3000	ROCK	.006	2024-T3	DRY	.1985	.0045
10	HSS #2	.194	3000	ROCK	.004	2024-T3	DRY	.1986	.0062
11	HSS #2	.194	3000	ROCK	.004	2024-T3	FREON	.1948	.0003
12	HSS #2	.194	3000	ROCK	.004	2024-R3	HE-2	.1959	.0010
13	**CAR #1	.190	3000	ROCK	.006	2024-T3	HE-2	.1900	.0010
14	CAR #1	.190	3000	ROCK	.006	2024-T3	FREON	.1906	.0019
15	CAR #4	.156	3000	ROCK	.008	2024-T3	HE-2	.1564	.0006
16	CAR #4	.156	3000	ROCK	.008	2024-T3	FREON	.1565	.0014
17	HSS #1	.190	500	QUACK	.004	Ti-662	HE-2	.1925	.0008
18	HSS #1	.190	500	QUACK	.004	Ti-662	FREON	.1927	.0006
19	HSS #1	.190	500	QUACK	.004	Ti-662	ISOPAR	.1926	.0004
20	CAR #3	.190	1200	QUACK	.003	Ti-662	ISOPAR	.1926	.0014
21	CAR #3	.190	1200	QUACK	.003	Ti-662	HE-2	.1920	.0010
22	CAR #3	.190	1200	QUACK	.003	Ti-662	FREON	.1924	.0015
23	HSS #1	.190	500	QUACK	.006	Ti-662	ISOPAR	.1920	.0006
24	HSS #1	.190	500	QUACK	.006	Ti-662	HE-2	.1920	.0003
25	HSS #1	.190	500	QUACK	.006	Ti-662	FREON	.1920	.0007
26	CAR #2	.190	3000	ROCK	.004	GRAPHITE/ EPOXY	WATER	.1894	.0009
27	CAR #2	.190	3000	ROCK	.003	GRAPHITE/ EPOXY	WATER	.1985	.0009

*HIGH-SPEED STEEL
**CARBIDE

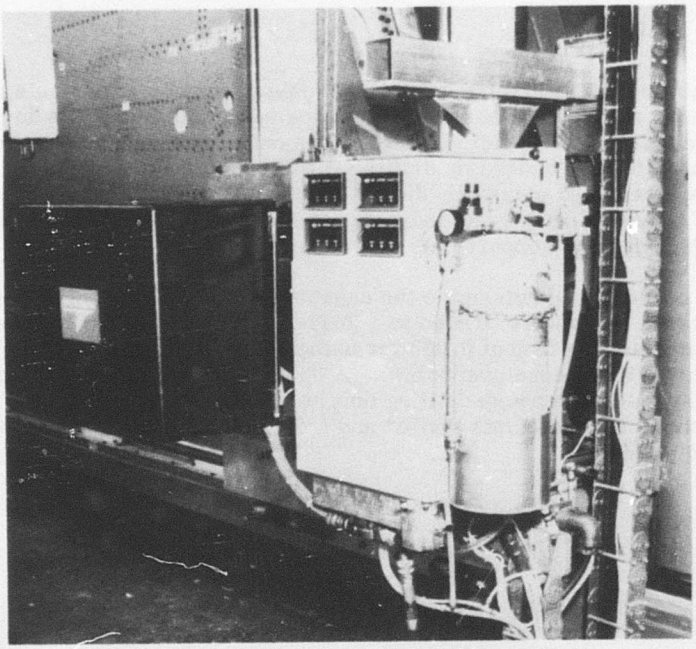


Figure 61. Coolant Tank Installation

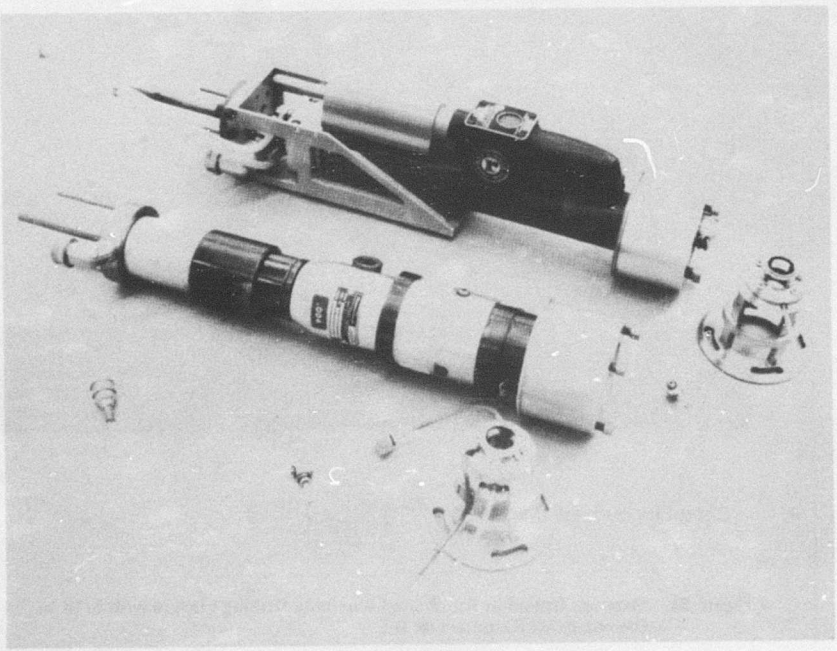


Figure 62. Nosepiece with Coolant Provision

Automated Assembly Drilling Fixture can equal the performance of portable drilling guns, that is, produce wing skin holes whose minimum-to-maximum diameters do not exceed 0.002 in. provided that a coolant fluid is used. The out-of-tolerance holes generated in Test Numbers 9 and 10 were caused by drilling without the assistance of coolant. Because the drill unit nosepieces used originally did not have bushing supports for the drill shafts, the hole diameter tolerance range was increased. The nosepiece developed for production contains a drill shaft bushing support plus other features.

Tests were conducted to determine the capacity of the Automated Assembly Drilling Fixture. Countersunk holes were drilled in a 2024-T3 aluminum alloy plate and a graphite/epoxy laminate at a feed of 0.003 ipr using a 2750-rpm Quackenbush drilling unit and 5/16-in. diameter drill/countersink bits. A Ti-6Al-6V-2Sn titanium alloy plate was drilled with a 450-rpm Quackenbush drilling unit at a feed of 0.003 ipr using the same size bits. Figure 63 shows the materials drilled and a drill/countersink bit with a countersink depth-stop adjustment nut.

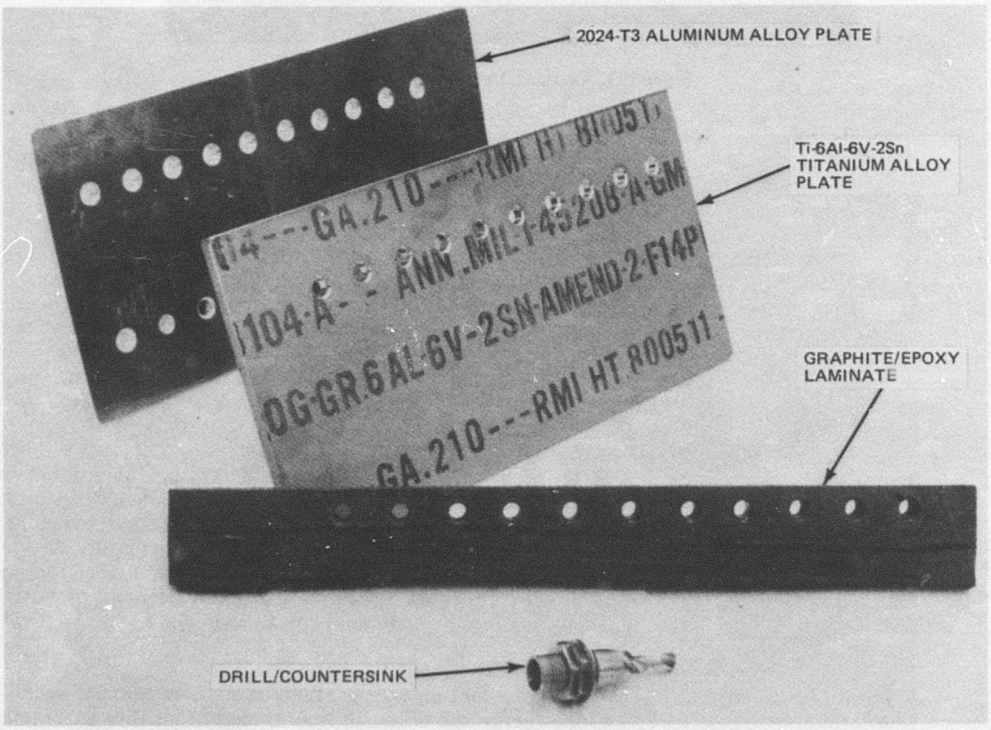


Figure 63. Materials Drilled in Automated Assembly Drilling Fixture with 5/16 In. Diameter Drill/Countersink Bit

2. Surface Roughness

Cross-sections of the drilled test plates (Table 8) were selected for evaluation of hole surface roughness. A Pilotar-Type AD profilometer was used to measure the internal surface finish of the drilled holes. To ensure accurate measurements, the instrument probe was first calibrated to a standard 250-rms surface finish, then fixtured behind a hole, and finally drawn into the hole to take the reading. Three readings per hole were taken and averaged. Data obtained are presented in Table 9.

Analysis of the test results shows that use of a coolant significantly reduces surface roughness (note greater surface roughness of holes drilled dry in Test No's. 9 and 10 compared with that of holes drilled with coolants). The high surface roughness obtained in Test No. 23 was caused by difficulty encountered in applying the coolant spray.

It should be noted that these holes were drilled with the development drill unit nosepiece which does not incorporate a bushing to reduce drill shaft end play. The production nosepiece should produce a measurably better and more consistent surface finish than the finishes shown in Table 9.

3. Correlation of Eddy Current with Hole Quality

A study was conducted to develop a rapid means for inspecting hole quality using eddy currents. It had been found that the conventional methods for taking dimensional measurements (size and out-of-roundness) using plug gauges and air gauges were time-consuming and limited because of accessibility requirements. It was also found that microscopic analyses of holes to determine the presence of cracks, grooves, notches and to determine general surface roughness was time-consuming. Visual inspection of areas inside the holes was also impossible without cross-sectioning the actual part. Surface roughness measurement using a profilometer was also limited, since it required a stable test setup, which precluded its use for many production applications. It was thought that a multi-frequency eddy current system, which would accentuate and suppress various signals, would be more effective. For example, effects due to lift-off (hole out-of-roundness) could be accentuated by using a low coil frequency (50 KHz). Recorder scans of eddy current impedance signals would be taken on cross-sections of holes which had small, medium, and large out-of-roundness, as evidenced by their hole diameter standard deviations (see Table 10).

Scans were taken using a multi-frequency Nortec NDT-3 eddy current instrument and absolute probe. The probe was then "nulled" to aluminum to maximize sensitivity to lift-off variations and scans were taken on each set of 20 holes. Figure 64 shows typical scans for the test configurations studied. It was found that out-of-roundness could be directly correlated to maximum deflection of the eddy current signal. This was expected since, at this frequency, variations in eddy currents would theoretically be most sensitive to lift-off. Table 10 gives the average, maximum eddy current signals for each test configuration.

It should be noted that the previous evaluation was performed using a manual technique which involved rotating the probe inside the hole. It was thought that this technique could be greatly improved by using an automated system, which in addition to having the advantage of minimizing operator dependence, would also scan the entire hole. An evaluation was, therefore, performed using an automated helical scanning device with a phase-sensitive eddy current system. The advantage of using this type of device was that

Table 9. Hole Surface Finish of Drilled Test Holes

Test No.*	Drill Dia, In.	Drill Mat'l	Cutting Speed, Ft/Min	Feed, ipr	Coolant	Average Surface Roughness, rms	Standard Deviation
2024-T3 Aluminum Alloy							
5	.248	HSS**	195	.006	Freon	22	± 5
6	.248	HSS	195	.006	HE-2	19	± 4
7	.194	HSS	152	.006	HE-2	35	± 12
8	.194	HSS	152	.006	Freon	30	± 8
9	.194	HSS	152	.006	Dry	68	± 14
10	.194	HSS	152	.004	Dry	75	± 57
11	.194	HSS	152	.004	Freon	23	± 7
12	.194	HSS	152	.004	HE-2	23	± 4
Ti-6Al-6V-2Sn Titanium Alloy							
17	.190	HSS	25	.004	HE-2	27	± 4
18	.190	HSS	25	.004	Freon	20	± 5
19	.190	HSS	25	.004	Isopar	28	± 9
23	.190	HSS	25	.006	Isopar	45	± 23
24	.190	HSS	25	.006	HE-2	31	± 8
25	.190	HSS	25	.006	Freon	28	± 8
20	.190	C-2***	60	.003	Isopar	34	± 9
21	.190	C-2	60	.003	HE-2	35	± 5
22	.190	C-2	60	.003	Freon	26	± 5
Hercules 3501/A-S Graphite/Epoxy Composite							
27	.190	C-2	150	.003	Water	40	± 9
26	.190	C-2	150	.004	Water	52	± 20

* Ref: Table 6
** High-Speed Steel
*** Carbide

Table 10. Summary of Eddy Current Tests

Test Configuration	Hole Diameter Std Deviation, 10^{-3} In.	Avg Max Eddy Current Std Dev, 10^{-3} In.	Max Avg Eddy Current Signal
X	0.080 (Small)	4.5	10
Y	3.29 (Medium)	6.5	14
Z	14.90 (Large)	17.5	15



Figure 64. Typical Scans for Test Configurations Studied

it allowed phase rotation of eddy current signals to maximize lift-off variations. Scans were then taken on selected holes. Results are summarized in Table 10. This technique reduced much of the noise produced by probe wobble and is recommended over any manual method.

A study was conducted to determine if a direct correlation existed between surface roughness values and eddy current signals. Holes having a wide range of surface roughness were checked with the automated helical scanning device and phase-sensitive eddy-current system, which operates at a high coil frequency (1,000 KHz), because it enhances surface effects. Although direct correlation between eddy current coil impedance and average profilometer surface roughness readings could not be obtained, the results obtained indicated that a usable correlation might be found with additional effort. It should be noted that this technique consistently detected grooves that were present in some holes, particularly those of Configuration Y which had high profilometer readings. Visual examination showed that 0.005-in.-deep grooves were present in these holes. A typical scan of a hole containing a groove is shown in Fig. 65. The "signature" for a groove is a sharp up-down deflection. It should also be noted that this technique can consistently detect shallow cracks about 0.005-in. deep. Although a crack signal would give an indication similar to that produced by the notch signal in Fig. 65, the indication would be made more rapidly and have a large deflection.

In summary, a rapid-scanning eddy-current system can probably be developed to determine out-of-roundness and the general surface condition of drilled holes. Additional development work is required, however, to generate a prototype production system.

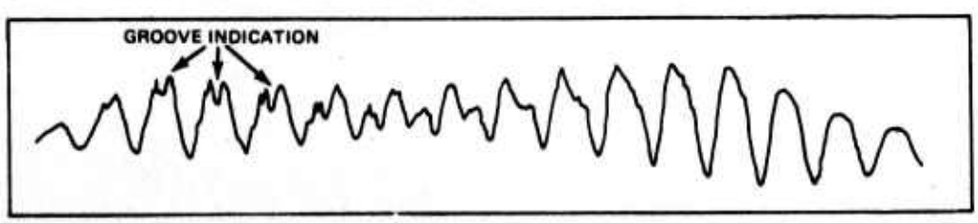


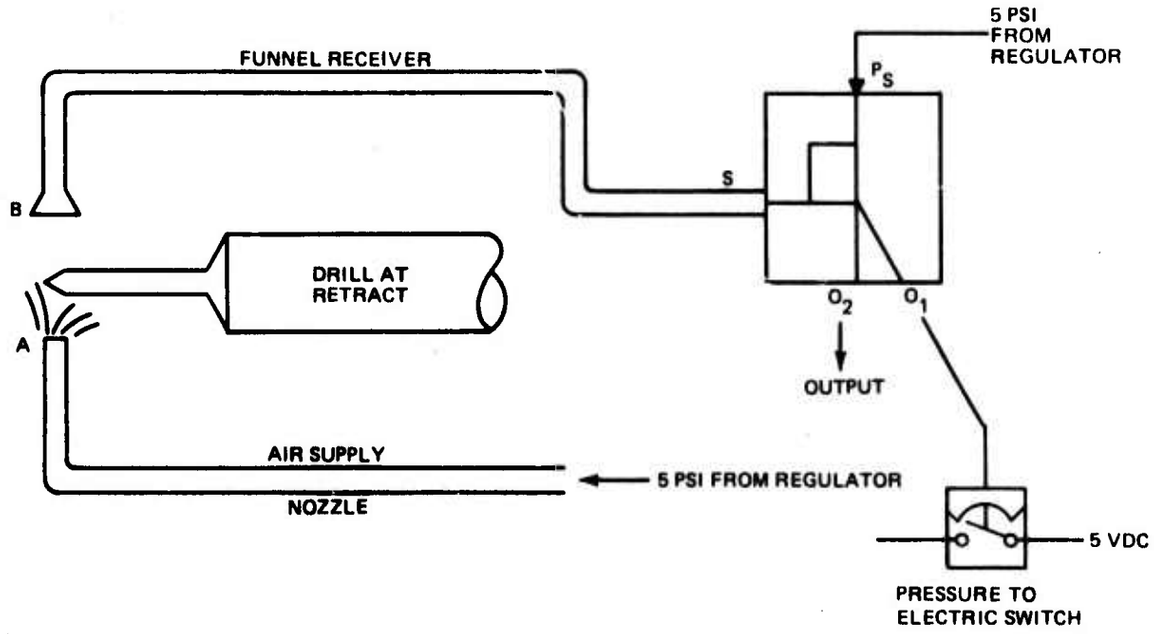
Figure 65. Grove Indications

4. Tool Failure Detection

The quality of holes drilled in an automated system is consistently good based on past experience. An automated drilling system will provide controlled operating conditions independent of the operator's skill. In the case of cutter failure, however, the same system may begin to produce poor-quality holes. To prevent this from happening, tool failure must be detected immediately. Accordingly, a fluidic circuit (Fig. 66) was set up to provide this capability. The fluidic circuit offered the least complex means of detection and did not substantially increase the size of the nosepiece.

The tool breakage detection circuit consists of a Corning fluidic back-pressure switch that normally reacts to a blockage of its sensing Port S. However, this port cannot be blocked by a rotating drill. A stream of 5-psig air is directed at the sensing port but is blocked by the drill whether the drill is rotating or stationary. If the forward end of the drill should break, the stream of air impinges on the sensing port causing the fluidic gate to change its output from O_2 to O_1 which, in turn, can be used to signal the computer.

The fluidic detection system was added to the Quackenbush nosepiece (Fig. 67 and 68). The system was bench-tested while the drill gun was operating under full coolant flow. The tool breakage detection system worked reliably; however, the primary system for detecting tool breakage is the elapsed timer.



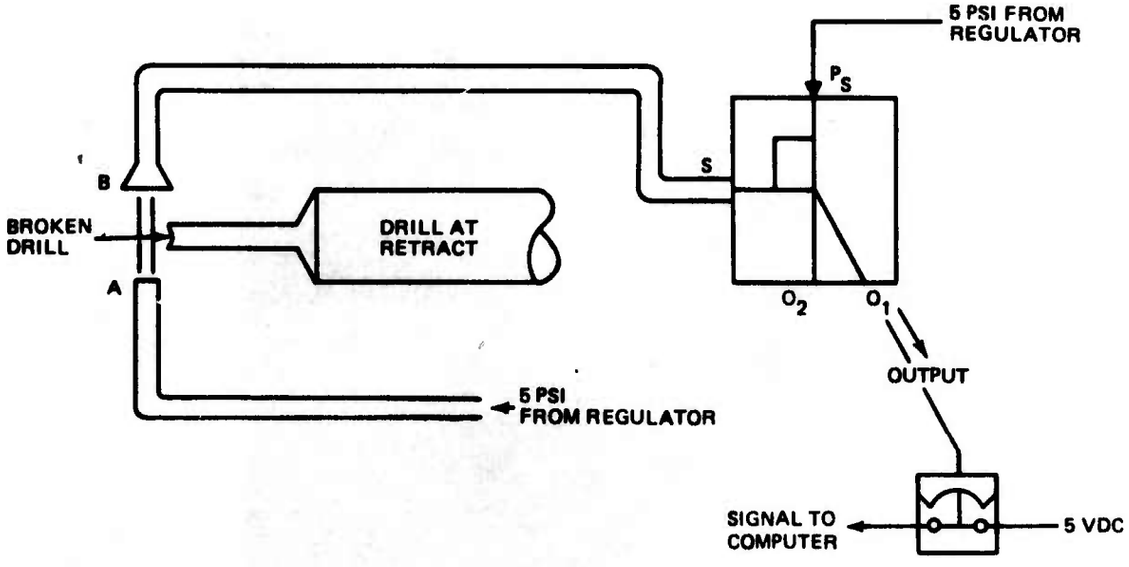


Figure 66. Tool Breakage Detection Circuit

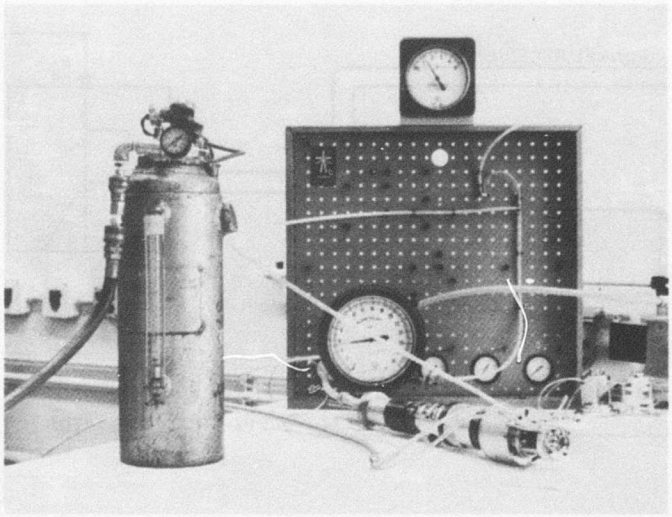


Figure 67. Quackenbush Drilling Unit With Fluidic Tool — Breakage Detection System

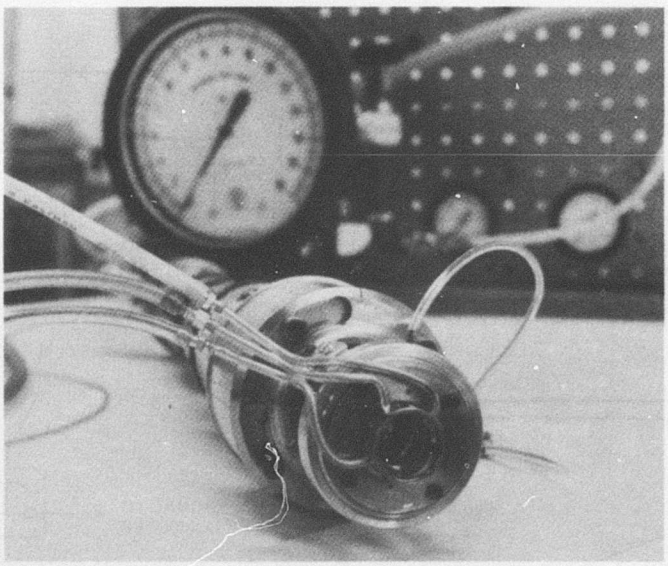


Figure 68. Close-up View of Quackenbush Nosepiece with Fluidic Detection System Installed

SECTION V

DEMONSTRATION AND COST ANALYSIS

A. INTRODUCTION

The technical and economic benefits of applying the Automated Assembly Fixture Drilling system to aircraft production were determined. This was accomplished with the assistance of production personnel, fulfilling a prime objective of the program to reduce the system to practice in a typical aircraft manufacturing operation.

B. DEMONSTRATION OF SYSTEM

The automated, five-axis drilling system was demonstrated by applying it to a production assembly drilling fixture that was previously used with conventional, manual drilling procedures. The assembly selected for the demonstration was the outer-wing upper cover of the A-6E aircraft (Fig. 2). This 5 x 16-ft all-aluminum structure has over 2,000 holes, ranging in diameter from 1/8 to 1/4 in. and over 1,000 blind fasteners. About 600 of these holes are drilled to a tolerance of ±0.001 in. Thickness of the 7075-T6 aluminum alloy wing cover ranges from 1/8 to 7/16 in. The substructure is painted with a fuel-protective, yellow-green polyurethane coating per MIL-C-27725. A production assembly fixture (Fig. 69) was modified to accept a 12-ft. vertical carriage and drill head assembly (Fig. 9). The software described in Subsection IIIF was used to program the drilling operation. An overview of the data file is shown in Fig. 29.

Drilling times for the first set of A-6E outer wing panel assemblies with the Automated Assembly Fixture Drilling systems are listed in Table 11. The longer drilling time for wing No. 77 resulted from the use of a 2,000-rpm Quackenbush drill unit in place of the previously used 3,000-rpm unit which was being repaired.

The average production time to manually set-up the hole template, locate the hole positions, and drill an A-6E wing panel is 65 hr. The Automated Assembly Fixture Drilling system performed the same task in about 25 hr. The two operations are compared in Fig. 70. Scanning and drilling are accomplished in a little less than 13 hr. The remaining time (setup) is used to remove the camera and install the drill unit, and to make 16 drill/countersink changes. The setup times shown in Table 11 include time to make a countersink depth adjustment on the developmental nosepiece that was difficult to accomplish. Use of the new production nosepiece will reduce setup time to no more than 5 to 7 hr. As production personnel become more familiar with the automated system, setup time will be reduced even further.

Table 11. Automatic Drilling Times for Production A-6E Wing Assemblies

Wing No.	Scan Time, Hr:Min	Drill Time, Hr:Min	Setup Time, Hr:Min	Drill Speed, RPM
69	2:40	9:50	15:20	3,000
72	2:40	10:05	13:45	3,000
73	2:40	9:54	13:15	3,000
77	2:35	11:38	10:50	2,000

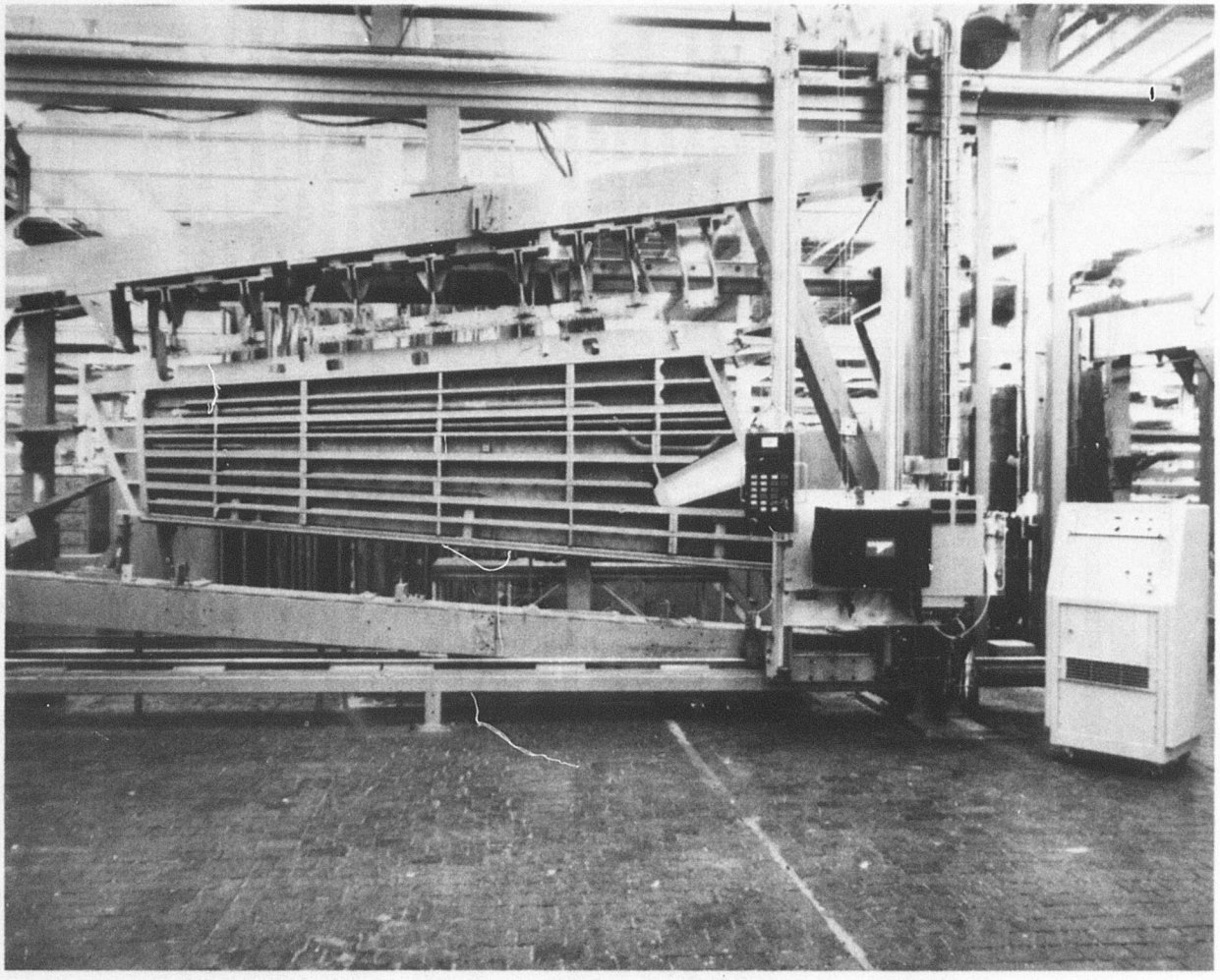


Figure 69. Production Assembly Drilling Fixture Modified to Accept Automated Five-Axis Drilling System

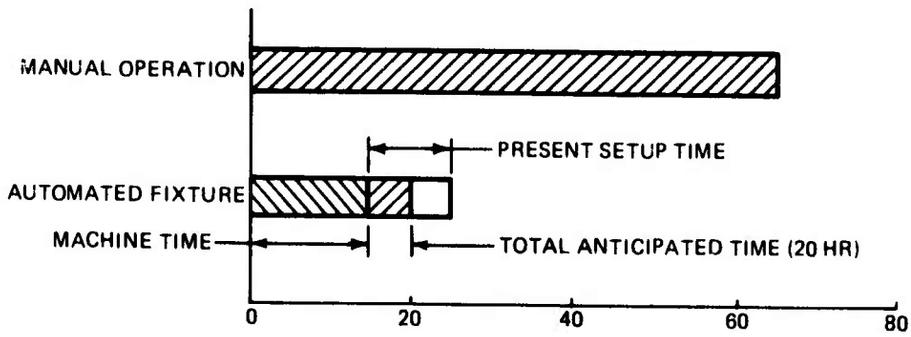


Figure 70. Comparison of Manual and Automated Drilling Fixtures

The Automated Assembly Drilling Fixture has been installed in the A-6E production line. This fixture contains the updated software, electronics, and production-type drill unit nosepiece.

C. AUTOMATED DRILLING COST DATA

The present Automated Assembly Drilling Fixture was built as a development item and, as such, does not reflect the economies of multiple purchase and fabrication. The major equipment cost areas of this unit are fixture modification, vertical gantry, drill head assembly, central control system, and remote interface box. The Reticon scan camera, its controller, and the drilling units are commercially available; prices can be obtained from the manufacturers concerned. The cost to fabricate adaptors for these units is $1,404. It should be noted that costs included in this section are based on labor rates of $18 per hour.

1. Fixture Modification

Modifications to the existing Automated Assembly Drilling Fixture will be required to make the fixture compatible with vertical gantries of various sizes. This will involve the addition of electrical hardware, cables, rails, drive and encoder racks, and power tracks. The costs to extend the fixture to specific lengths are shown in Table 12. Each fixture has a base modification cost for electrical equipment and cable hardware of $3,440. This cost can be spread over several fixtures if the plant layout permits the in-line installation of these fixtures and if the fixtures will not be used simultaneously (that is, as far as the Automated Assembly Drilling Fixture is concerned).

Table 12. Modification Costs for Various Sized Fixtures

TYPE OF COST	FIXTURE LENGTH, FEET			
	20	30	40	50
FIXED	$3,440	$3,440	$3,440	$3,440
SIZE DEPENDENT	$3,600	$5,400	$7,200	$9,000
TOTAL	$7,040	$8,840	$10,640	$12,440

2. Vertical Gantry

This module includes the X-axis drive system, vertical ways, drive rack, encoder rack, power track, control pendant, and electrical components and hardware. The cost of such an assembly for a 12-foot-high gantry is $21,600. An increase or decrease of 6 ft. in the height of the gantry would result in corresponding addition or reduction of $1,400 in this cost.

3. Drill Head Assembly

This module includes the mechanical/electrical components needed to provide four axes of motion (X, Y, Alpha, and Beta) to the drill/camera head. This module also houses the fluidic and pneumatic controls that operate the Z-axis and the drill unit. The cost of this assembly is $16,100.

4. Central Control System

This system consists of the basic minicomputer and disc storage that comprises the Central Controller which can simultaneously control up to eight gantries. As a result, the cost per gantry is a function of the number of gantries being controlled. The cost of this system is $23,000.

5. Remote Interface Box

The Central Controller communicates with each fixture through a remote interface box located at each fixture. One remote interface box is required at each operating gantry. The cost of one box is $18,900.

D. COST TRADEOFFS

1. Manual Versus Automated

Use of the Automated Assembly Drilling Fixture on the A-6E wing outer panel assembly reduced production labor by 60 percent. This system is applicable to any assembly fixture drilling operation that cannot be done on an automated drilling-and-riveting machine. Manual and automated drilling costs are compared in Fig. 71. The cost relationships shown were derived by using a $72,140 base-cost for the Automated Assembly Drilling Fixture and amortizing the costs of the central controller and scan camera over four gantries. Four out of the possible eight hantries that can be operated by the central controller were selected as an average requirement. The cost-per-hole range for the Automated Assembly Drilling Fixture shown in Fig. 71 represents the cost already incurred in the first four wings drilled and the near-term improvement depicted in Fig. 70.

2. Adaptive Sensing and Rapid Advance

The experience gained in automated drilling of the A-6E wing outer panels indicates that the addition of certain features to the Automated Assembly Drilling Fixture would produce savings that would outweigh the initial cost of these items. The average time to scan and drill the first few A-6E production wings is shown in Fig. 72. Near-term improvements to the fixture could result in the time savings indicated. A breakdown of the drilling cycle is shown in Fig. 73. Application of adaptive sensing and rapid advance to the drill/countersink cycle would reduce operating time by 25 percent while using

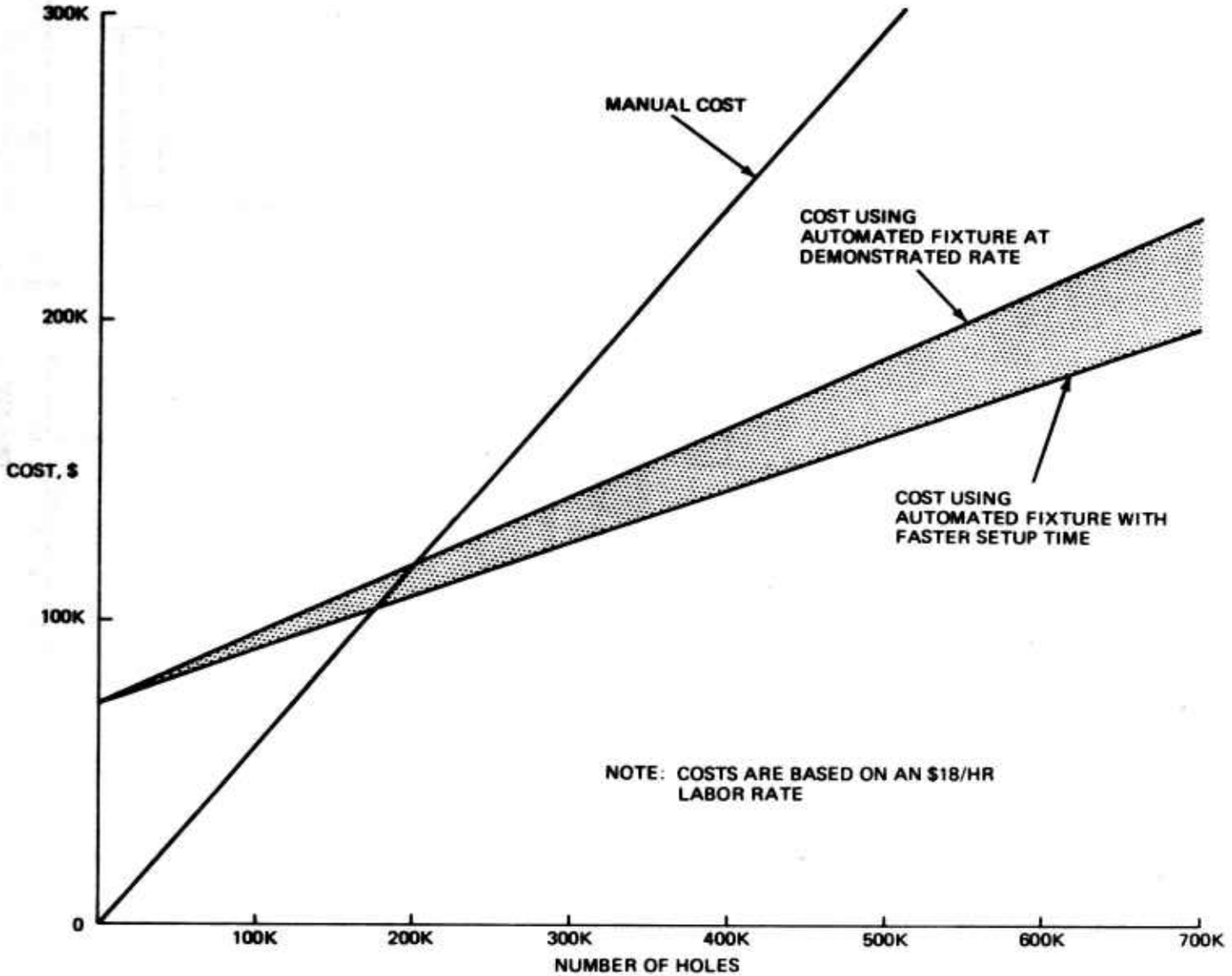


Figure 71. Comparison of Manual and Automated Fixture Drilling Costs

standard cutters. Use of adpative sensing and rapid advance for titanium structures would be well worth the initial investment because of the slow speeds and feeds imposed by this material.

3. Translational Speed Improvement

Substitution of DC servo motors with the accompanying logic for the existing X and Y, stepper drive motors could double the present translational speed of 120 in./min., thereby reducing the drill/scan time by two hours (see Fig. 72). In building a new fixture, initial inclusion of servo motors that cost about twice as much as the currently used stepper motors would reduce production operating times without significantly increasing the overall cost of the fixture. These savings would be realized in both the scanning and drilling cycles.

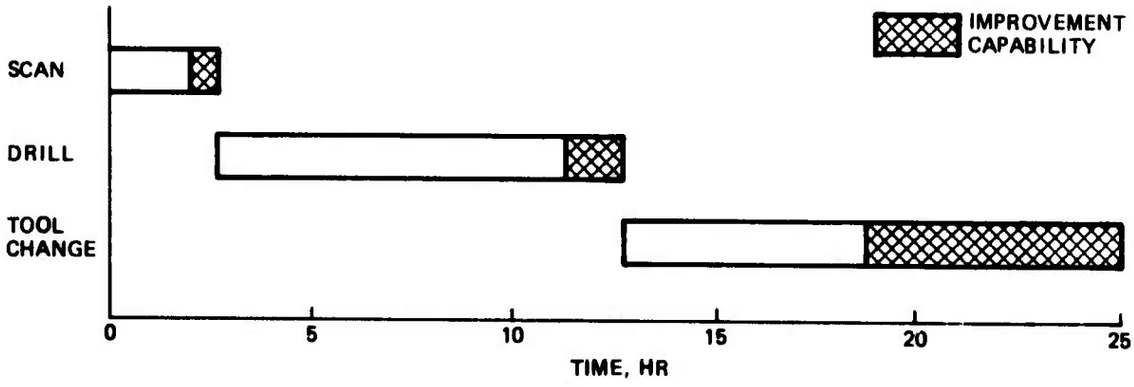


Figure 72. Automated Assembly Drilling Times for A-6E Wing

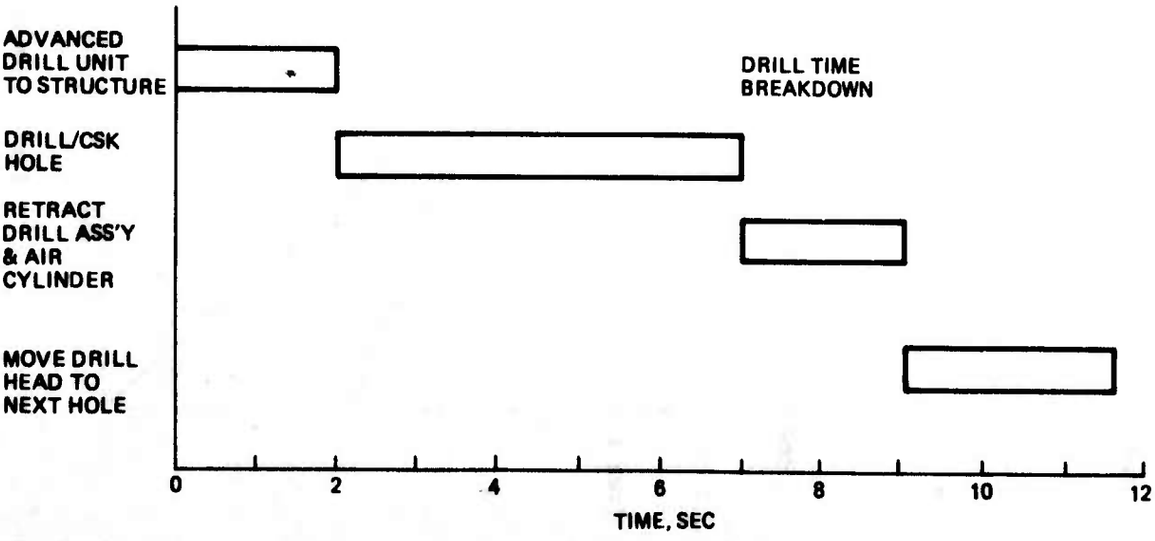


Figure 73. Hole Drilling Cycle Time (A-6E Fixture)

APPENDIX A

AUTOMATED ASSEMBLY FIXTURE

PROCESS SPECIFICATION

30 APRIL 1976

1. SCOPE

This specification establishes the procedures necessary for operating the five-axis automated drilling unit on an assembly fixture.

2. APPLICABLE DOCUMENTS

2.1 GRUMMAN AEROSPACE CORPORATION DOCUMENTS

Interim Technical Reports, In-806-5 (I), (II) and (III), Automated Assembly Fixture Drilling, Contract No. F33615-75-C-5192.

Five-Axis Automated Assembly Drilling System Operation and Maintenance Manual

2.2 DIGITAL EQUIPMENT CORPORATION DOCUMENTS

OS/8 Handbook (DEC-S8-OSHBA-A-D), April 74

3. REQUIREMENTS

A master coordinate data file (MCDF) is required. This file (see Fig. A-1 for specimen) must contain the coordinates of the holes to be drilled in the order that the drilling is to be done. The coordinates must be in the reference system of the assembly fixture to which it applies. The data should be punched on eight-channel punched tape (mylar or paper). Coordinate information must be preceded by an 'N' and have an arbitrary but unique 'N' number between the 'N' and the comma. The coordinate axis information need not be repeated between coordinates if those axis values do not change. Axis values are given in any order and must be prefixed with the axis description letter ('x', 'y', 'A', 'B', or 'Z'). A coordinate identification number is required for each coordinate; it shall be preceded with a '#', the numbers shall start at 10 and increment by 10. Blanks may be freely inserted, and comments may be inserted by preceding them by a slash '/' and ending them with a carriage return.

4. EQUIPMENT AND SOFTWARE

The following equipment is required to automate the drilling on the assembly fixture: a five-axis system as outlined in Table I of this report.

The following software is required to prepare the master coordinate map and to activate the five-axis control system:

- OS/8 software package (a leased package from Digital Equipment Corp.)
- Parts Programmer System Software (PPSS), Version A, supplied by Grumman Aerospace Corporation
- Run-Time System Software (RTSS), Version A, supplied by Grumman Aerospace Corporation.

A6E UPPER COVER OUTER PANEL
LEFT HAND

```
N 1 ,    X  13.750  Y   8.378  A 0.102  B-0.027  Z 7.948  #   10 ;
N 2 ,    X  14.834  Y   8.512  A 0.101           Z 7.968  #   20 ;
N 2.1 ,  X  35.140  Y   9.469                    Z 6.494  #   30 ;
N 3 ,    X  35.139  Y   9.511                    Z 8.398  #   40 ;
N 4 ,    X  36.139  Y   9.571                    Z 8.427  #   50 ;
N 5 ,    X  37.226  Y   9.566                    Z 8.447  #   60 ;
N 5.1 ,  X  51.464  Y  10.311  A 0.102           Z 6.493  #   70 ;
N 6 ,    X  51.461  Y  10.432                    Z 8.759  #   80 ;
N 7 ,    X  52.496  Y  10.488  A 0.101           Z 8.769  #   90 ;
N 8 ,    X  53.550  Y  10.567                    Z 8.789  #  100 ;
N 8.1 ,  X  77.306  Y  11.736  A 0.102           Z 6.493  #  110 ;
N 9 ,    X  77.422  Y  11.857                    Z 9.316  #  120 ;
N 10 ,   X  78.398  Y  11.909  A 0.101           Z 9.326  #  130 ;
N 11 ,   X  79.511  Y  11.969                    Z 9.345  #  140 ;
N 11.1 , X 107.571  Y  13.513                    Z 6.494  #  150 ;
N 12 ,   X 107.574  Y  13.499                    Z 9.951  #  160 ;
N 13 ,   X 108.966  Y  13.575                    Z 9.980  #  170 ;
N 14 ,   X 110.260  Y  13.639                    Z10.009  #  180 ;
N 14.1 , X 129.621  Y  14.654                    Z 6.494  #  190 ;
N 15 ,   X 129.618  Y  14.768                    Z10.429  #  200 ;
N 16 ,   X 131.056  Y  14.839  A 0.102           Z10.458  #  210 ;
N 17 ,   X 132.387  Y  14.914  A 0.100           Z10.479  #  220 ;
N 17.1 , X 162.289  Y  16.412  A 0.102           Z 6.493  #  230 ;
N 18 ,   X 162.443  Y  16.510                    Z11.132  #  240 ;
N 19 ,   X 163.171  Y  16.543  A 0.101           Z11.142  #  250 ;
N 20 ,   X 163.882  Y  16.585                    Z11.162  #  260 ;
N 20.1 , X 167.769  Y  15.491  A 0.122  B-0.028  Z 6.494  #  270 ;
N 21 ,   X 167.759  Y  15.499                    Z11.386  #  280 ;
N 22 ,   X 167.368  Y  14.599  A 0.137  B-0.029  Z11.495  #  290 ;
N 23 ,                                           Z 6.495  #  300 ;
N 24 ,   X 168.132  Y  21.260  A 0.043  B-0.024  Z10.926  #  310 ;
N 278 ,  X  15.737  Y   8.476  A 0.101           Z 7.988  # 3090 ;
N 279 ,  X  16.502  Y   8.545                    Z 7.998  # 3100 ;
N 280 ,  X  17.374  Y   8.641                    Z 8.017  # 3110 ;
N 281 ,  X  18.271  Y   8.682                    Z 8.037  # 3120 ;
N 282 ,  X  19.160  Y   8.725                    Z 8.056  # 3130 ;
N 283 ,  X  19.928  Y   8.765                    Z 8.076  # 3140 ;
N 284 ,  X  20.802  Y   8.808                    Z 8.095  # 3150 ;
N 285 ,  X  21.687  Y   8.851                    Z 8.115  # 3160 ;
N 286 ,  X  22.573  Y   8.835  A 0.102           Z 8.134  # 3170 ;
N 287 ,  X  23.791  Y   8.958  A 0.101           Z 8.154  # 3180 ;
N 288 ,  X  25.022  Y   9.014                    Z 8.183  # 3190 ;
N 289 ,  X  26.261  Y   9.075                    Z 8.213  # 3200 ;
N 290 ,  X  27.533  Y   9.140                    Z 8.242  # 3210 ;
N 291 ,  X  28.858               A 0.102         Z 8.271  # 3220 ;
N 292 ,  X  30.148  Y   9.261  A 0.101           Z 8.291  # 3230 ;
N 293 ,  X  31.388  Y   9.327                    Z 8.320  # 3240 ;
N 294 ,  X  32.665  Y   9.391                    Z 8.349  # 3250 ;
N 295 ,  X  33.948  Y   9.393  A 0.102           Z 8.378  # 3260 ;
N 296,   X  39.332  Y   9.652                    Z 8.486  # 3270 ;
N 297 ,  X  40.498  Y   9.800  A 0.101           Z 8.515  # 3280 ;
N 298 ,  X  42.086  Y   9.899                    Z 8.554  # 3290 ;
N 299 ,  X  43.805  Y   9.997                    Z 8.584  # 3300 ;
N 300 ,  X  45.396  Y  10.024  A 0.102           Z 8.622  # 3310 ;
N 301 ,  X  46.968  Y  10.183  A 0.101           Z 8.652  # 3320 ;
N 302 ,  X  48.441  Y  10.265                    Z 8.681  # 3330 ;
N 302.1  X  49.895  Y  10.300                    Z 6.494  # 3340 ;
N 303 ,  X  49.858  Y  10.342                    Z 8.720  # 3350 ;
N 304 ,  X  46.069  Y  15.465  A 0.060  B-0.025  Z 8.207  # 3360 ;
N 305 ,  X  44.059  Y  15.394  A 0.061           Z 8.168  # 3370 ;

N 306 ,  X  41.9
N 307 ,  X  39.8
N 308 ,  X  37.7
N 309 ,  X  36.1
N 310 ,  X  30.7
N 311 ,  X  28.9
N 312 ,  X  27.3
N 313 ,  X  25.6
N 314 ,  X  20.4
N 315 ,  X  19.4
N 316 ,  X  18.5
N 317 ,  X  17.6
N 318 ,  X  16.6
N 319 ,  X  16.4
N 320 ,  X  17.2
N 321 ,  X  18.5
N 322 ,  X  19.7
N 323 ,  X  20.1
N 324 ,  X  21.6
N 325 ,  X  24.8
N 326 ,  X  26.6
N 327 ,  X  28.3
N 328 ,  X  30.0
N 329 ,  X  31.8
N 330 ,  X  35.6
N 331 ,  X  37.5
N 332 ,  X  39.3
N 333 ,  X  41.3
N 334 ,  X  43.3
N 335 ,  X  45.2
N 336 ,  X  47.2
N 336.1 , X  51.1
N 337 ,
N 337.1  X  68.2
N 338 ,  X  68.2
N 339 ,  X  66.9
N 340 ,  X  65.5
N 341 ,  X  64.2
N 342 ,  X  59.2
N 343 ,  X  58.1
N 344 ,  X  56.8
N 345 ,  X  55.5
N 346 ,  X  54.2
N 347 ,  X  53.0
N 348 ,  X  51.8
N 349 ,  X  50.6
N 350 ,  X  49.5
N 351 ,  X  48.5
N 352 ,  X  47.5
N 353 ,  X  46.4
N 354 ,  X  55.7
N 355 ,  X  53.8
N 356 ,  X  47.9
N 357 ,  X  46.0
N 358 ,  X  44.0
N 359 ,  X  42.1
N 360 ,  X  40.8
N 361 ,  X  39.7
N 362 ,  X  36.1
```

PANEL

# 10 ;	N 306 ,	X	41.992	Y	15.324			Z 8.119	# 3380 ;
# 20 ;	N 307 ,	X	39.851	Y	15.243			Z 8.070	# 3390 ;
# 30 ;	N 308 ,	X	37.733	Y	15.173			Z 8.021	# 3400 ;
# 40 ;	N 309 ,	X	36.193	Y	15.108			Z 7.982	# 3410 ;
# 50 ;	N 310 ,	X	30.733	Y	14.904			Z 7.865	# 3420 ;
# 60 ;	N 311 ,	X	28.983	Y	14.847			Z 7.816	# 3430 ;
# 70 ;	N 312 ,	X	27.397	Y	14.790			Z 7.787	# 3440 ;
# 80 ;	N 313 ,	X	25.688	Y	14.724			Z 7.748	# 3450 ;
# 90 ;	N 314 ,	X	20.472	Y	14.509			Z 7.631	# 3460 ;
# 100 ;	N 315 ,	X	19.481	Y	14.473			Z 7.601	# 3470 ;
# 110 ;	N 316 ,	X	18.544	Y	14.432			Z 7.582	# 3480 ;
# 120 ;	N 317 ,	X	17.600	Y	14.399			Z 7.562	# 3490 ;
# 130 ;	N 318 ,	X	16.668	Y	14.367			Z 7.543	# 3500 ;
# 140 ;	N 319 ,	X	16.473	Y	15.234	A 0.055		Z 7.476	# 3510 ;
# 150 ;	N 320 ,	X	17.208	Y	15.264			Z 7.495	# 3520 ;
# 160 ;	N 321 ,	X	18.559	Y	15.286			Z 7.515	# 3530 ;
# 170 ;	N 322 ,	X	19.293	Y	15.326			Z 7.534	# 3540 ;
# 180 ;	N 323 ,	X	20.109	Y	15.353			Z 7.554	# 3550 ;
# 190 ;	N 324 ,	X	21.679	Y	15.428			Z 7.593	# 3560 ;
# 200 ;	N 325 ,	X	24.861	Y	15.548			Z 7.671	# 3570 ;
# 210 ;	N 326 ,	X	26.615	Y	15.616			Z 7.710	# 3580 ;
# 220 ;	N 327 ,	X	28.332	Y	15.677			Z 7.739	# 3590 ;
# 230 ;	N 328 ,	X	30.036	Y	15.734			Z 7.779	# 3600 ;
# 240 ;	N 329 ,	X	31.896	Y	15.807			Z 7.827	# 3610 ;
# 250 ;	N 330 ,	X	35.659	Y	16.014	A 0.054		Z 7.915	# 3620 ;
# 260 ;	N 331 ,	X	37.550	Y	16.022	A 0.055		Z 7.964	# 3630 ;
# 270 ;	N 332 ,	X	39.344	Y	16.092			Z 8.003	# 3640 ;
# 280 ;	N 333 ,	X	41.341	Y	16.182	A 0.054		Z 8.052	# 3650 ;
# 290 ;	N 334 ,	X	43.308	Y	16.313			Z 8.091	# 3660 ;
# 300 ;	N 335 ,	X	45.299	Y	16.386			Z 8.140	# 3670 ;
# 310 ;	N 336 ,	X	47.267	Y	16.470			Z 8.179	# 3680 ;
# 3090 ;	N 336.1 ,	X	51.172	Y	16.593			Z 6.499	# 3690 ;
# 3100 ;	N 337 ,			Y	16.601			Z 8.267	# 3700 ;
# 3110 ;	N 337.1	X	68.276	Y	21.995	A 0.023	B-0.024	Z 6.495	# 3710 ;
# 3120 ;	N 338 ,	X	68.277	Y	22.028			Z 8.487	# 3720 ;
# 3130 ;	N 339 ,	X	66.953	Y	22.004			Z 8.458	# 3730 ;
# 3140 ;	N 340 ,	X	65.549	Y	21.978			Z 8.419	# 3740 ;
# 3150 ;	N 341 ,	X	64.251	Y	21.944			Z 8.389	# 3750 ;
# 3160 ;	N 342 ,	X	59.297	Y	21.862	A 0.024		Z 8.272	# 3760 ;
# 3170 ;	N 343 ,	X	58.100	Y	21.841			Z 8.243	# 3770 ;
# 3180 ;	N 344 ,	X	56.850	Y	21.734			Z 8.213	# 3780 ;
# 3190 ;	N 345 ,	X	55.544	Y	21.787			Z 8.184	# 3790 ;
# 3200 ;	N 346 ,	X	54.268	Y	21.765			Z 8.155	# 3800 ;
# 3210 ;	N 347 ,	X	53.024	Y	21.743			Z 8.126	# 3810 ;
# 3220 ;	N 348 ,	X	51.800	Y	21.710			Z 8.096	# 3820 ;
# 3230 ;	N 349 ,	X	50.606	Y	21.603			Z 8.067	# 3830 ;
# 3240 ;	N 350 ,	X	49.565	Y	21.647			Z 8.038	# 3840 ;
# 3250 ;	N 351 ,	X	48.535	Y	21.616			Z 8.018	# 3850 ;
# 3260 ;	N 352 ,	X	47.501	Y	21.594			Z 7.989	# 3860 ;
# 3270 ;	N 353 ,	X	46.455	Y	21.576			Z 7.969	# 3870 ;
# 3280 ;	N 354 ,	X	55.771	Y	27.723	A-0.005		Z 8.136	# 3880 ;
# 3290 ;	N 355 ,	X	53.806	Y	27.718			Z 8.088	# 3890 ;
# 3300 ;	N 356 ,	X	47.977	Y	27.699			Z 7.951	# 3900 ;
# 3310 ;	N 357 ,	X	46.025	Y	27.691			Z 7.902	# 3910 ;
# 3320 ;	N 358 ,	X	44.048	Y	27.695			Z 7.853	# 3920 ;
# 3330 ;	N 359 ,	X	42.148	Y	27.655			Z 7.814	# 3930 ;
# 3340 ;	N 360 ,	X	40.852	Y	27.701			Z 7.785	# 3940 ;
# 3350 ;	N 361 ,	X	39.708	Y	27.690			Z 7.756	# 3950 ;
# 3360 ;	N 362 ,	X	36.189	Y	27.691			Z 7.697	# 3960 ;
# 3370 ;									

Figure A-1 Master Coordinate Data File

5. PERSONNEL QUALIFICATIONS

Personnel who make changes to the data file should have the same qualifications as those for parts programmers for N/C machines.

Personnel who operate the drilling equipment should have the qualifications of a qualified assembler mechanic.

Personnel who activate or deactivate the central computer should be supervisors or parts programmers.

6. POWERING-UP CONTROL COMPUTER AND REMOTE INTERFACE BOX (RIB)

6.1 TURNING ON

When the RTSS is to be continued from the point at which it was running prior to turning computer off as in Section 7 below, perform the following steps:

- Be sure that 'HALT' switch on the computer (CPU) is in the up position.
- Turn CPU key switch to 'POWER' position
- Turn the teletype to 'ON'
- Depress top of 'RUN' switch on disc unit. When the disc comes up to speed (approximately 20 sec), the program will commence running at the point at which it was previously shut down
- Turn key switch on remote interface box (RIB) to 'ON' and depress the 'MACHINE POWER ON' switch. Depress the 'CONTINUE' switch on the control pendant to resume scanning or drilling.

When power is to be brought up without having the program running, put the 'HALT' switch on the computer in the down position, then follow the first four steps above.

6.2 RETURNING CONTROL TO THE OS/8 KEYBOARD MONITOR

This will be required whenever another program is to be run (such as editing or creating the master coordinate map) or reloading a program. To return control to the OS/8 keyboard monitor, depress and then raise the 'HALT' switch. Raise and lower the bootstrap switch. The teletype should respond by printing a period; await commands on the keyboard.

6.3 ACTIVATING RUN-TIME SYSTEM SOFTWARE (RTSS)

When the OS/8 keyboard monitor is in main memory and executing, a supervisor will type in 'R RTSS' followed by a carriage return. All drilling gantries (up to eight) can then be operated.

7. POWERING DOWN

When the following procedure is followed, the drilling or scanning cycles can be resumed by following the instructions of Subsection 6.1.1:

- Return all active gantries to zero via the procedure outlined in Subsection 11.2
- Turn power off on remote interface box (RIB)
- Depress bottom portion of switch on disc drive marked 'LOAD'
- Turn CPU key switch to 'OFF'.

8. CREATION OF MASTER COORDINATE MAP (MCM)

The master coordinate map is used by the RTSS to define the nominal hole position. The MCM is constructed from the master coordinate source file (MCSF) by running it with the parts programmer system software (PPSS). The MCSF is constructed from the master coordinate data file (MCDF) described in Section 3.

8.1 LOADING THE MCDF ONTO DISC.

Allow the OS/8 keyboard monitor to assume control as in Subsection 6.2 above. Read the MCDF onto the disc using the OS/8 PIP program described in the OS/8 handbook (Page 1-97). A partial listing of this file is shown in Fig. A-1.

8.2 CONSTRUCTING THE MCSF

The MCDF, now resident on the disc, is edited to include the mnemonics necessary to describe what holes are to be scanned, insertion of control moves, and defining of Cleco holes. The mnemonics available and their use and restrictions are described in Subsection IIIF4 of this report. The file is edited using either the OS/8 'EDIT' program or the OS/8 "TECO' program described in the OS/8 handbook beginning on pages 1-78 and 2-132, respectively. After editing, the section of the MCSF might be as shown in Fig. A-2.

8.3 CONSTRUCTING THE MCM

The master coordinate map is constructed by running the PPSS program using the MCSF as an input file. To run the PPSS program, control is first given to the OS/8 keyboard monitors. The parts programmer then types in 'R PPSS' followed by a carriage return. The PPSS will print an asterisk in the left-hand column, at which time the file names are entered. Subsections IIIF3 and IIIF4 of this report describe the conventions required for file names. When the PPSS has completed its task, it will return control to the OS/8 keyboard monitor. The five-axis run-time system software (RTSS) can then be recalled as described in Subsection 6.3.

9. SCANNING

Once the RTSS is executing and a MCM has been formed, the structure can be scanned by performing the following functions:

- Move all axes to zero position by putting control pendant in 'MANUAL' and using the 'JOG' Jog Stick to position X and Y and then Alpha and Beta. Selection switches are provided on the control pendant to select the axis that the Jog Stick controls

- Put the scan camera into position in the annular cylinder and make the electrical connection

- Set up control pendant for scanning by selecting 'AUTO', 'SCAN', and 'HOLES'. Set thumbwheel switches for the starting hole and finishing hole. Depress 'DATA LOAD'. When the display says 'SYSTEM INITIALIZED', depress 'CYCLE START'.

10. DRILLING

Once the RTSS is executing and a scan run has been made, the skin can be put into position and drilling can commence:

- Move all axes to zero as in Subsection 9.1

- Put drill into position in the annular cylinder and make pneumatic connection

- Put drill bit into drill for the operation to be performed. An operation sheet similar to the one shown before for the Grumman A-6E upper wing cover should be used

- Set up control pendant for drilling by selecting 'AUTO', 'DRILL', 'FINISH HOLES' or 'CLECO HOLES', and 'HOLES'. Set thumbwheel switches to the starting hole and finishing hole. Depress 'DATA LOAD'. When the display says 'SYSTEM INITIALIZED', depress 'CYCLES START'.

11. CYCLE INTERRUPTION

11.1 CYCLE STOP

The drilling cycle can be interrupted by depressing the 'CYCLE STOP' button on the control pendant. If the gantry was moving. It will stop when it reaches its next coordinate point. If it was drilling or scanning, it stops after drilling or scanning at that point. Continuing from a STOP condition can be done by pressing the 'CONTINUE' switch on the control pendant.

11.2 RETURNING TO ZERO

When the gantry is in a CYCLE STOP state, depressing the 'RETURN TO ZERO' switch on the control pendant will cause all axes to return to their home positions. The unit can be continued from this point by depressing 'CONTINUE' as in Subsection 11.1.

11.3 JOG CONTROL in auto

When the gantry is in a CYCLE STOP state, any axis can be jogged in MANUAL using the JOG Jog Stick. The control system will keep track of the axis positions. The 'CONTINUE' switch can be depressed as in Subsection 11.1 above, and the gantry will proceed to the correct position.

```
/                A6E UPPER COVER OUTER PANEL
/                      LEFT HAND
/
/                REVISED 8/17/76     1PM  WG
/                REVISED 8/5/76     11AM
/                REVISED 8/2/76      1PM
/                REVISED 7/30/76
/
/
/        DRILL DIAMETER TABLE
/
/   DD00=0.063
/   DD01=0.093
/   DD02=0.127
/   DD03=0.156
/   DD04=0.187
/   DD05=0.250
/   DD06=0.375
/   DD07=0.50
/   DD08=?
/   DD09=?
/   DD10=0.190
/   DD11=0.251
/   DD12=0.189
/   DD13=0.192
/   DD14=0.160
/   DD15=?
/
/        EDGE DISTANCE TABLE
/
/   ED00=0.625
/   ED01=0.437
/   ED02=0.25
/   ED03=0.3125
/   ED04=0.375
/   ED05=0.5
/   ED06=0.75
/   ED07=0.562
/   ED08=?
/   ED09=?
/   ED10=0.375
/   ED11=0.375
/   ED12=0.375
/   ED13=0.375
/   ED14=0.375
/   ED15=0.375
/
/        SKIN THICKNESS COEFFICIENT TABLE
/
/   ST00= X0
/   ST01= X0.1
/   ST05= X0.5
/   ST07= X0.7
/   ST10= X1.0
/   ST15= X1.5
/   ST20= X2.0
/   ST25= X2.5
 B
/
/        @@@@@1@@@@@@@@@@@@@@@@@@
/
```

```
/        ******  OPERA
/  CLECO, OR TACK RUN
/
/        @@@@@@@@@@@@@@
  OP=01,
 ED01, DD10, EGBR, ANGL
     N 1 ,       X  13
 SCN1,
     N 2 ,       X  14.
 SCN2, CMS,
     N 2.1 ,     X  35.
 SCN0, FCMS,
     N 3 ,       X  35.
 SCN1,
     N 4 ,       X  36.
     N 5 ,       X  37
 SCN2, CMS,
     N 5.1 ,     X  51
 ED04,  SCN0, FCMS,
     N 6 ,       X  51.
     N 7 ,       X  52.
 SCN1,
     N 8 ,       X  53.
 SCN2, CMS,
     N 8.1 ,     X  77
 SCN0, FCMS,
     N 9 ,       X  77.
     N 10 ,      X  78.
 SCN1,
     N 11 ,      X  79
 SCN2, CMS,
     N 11.1 ,    X 107.
 SCN0, FCMS,
     N 12 ,      X 107
 SCN1,
     N 13 ,      X 108.
     N 14 ,      X 110
 SCN2, CMS,
     N 14.1 ,    X 129.
 SCN0, FCMS,
     N 15 ,      X 129
 SCN1,
     N 16 ,      X 131.
 SCN0,
     N 17 ,      X 132.
 SCN2, CMS,
     N 17.1 ,    X 162.
 SCN0, FCMS,
     N 18 ,      X 162.
     N 19 ,      X 163.
 SCN1,
     N 20 ,      X 163.
 SCN2, CMS,
     N 20.1 ,    X 167.
 EGTL, ED03, ANGL= 6
     N 21 ,      X 167.
     N 22 ,      X 167.
                 CMD, SC
     N 23 ,
 ANGL=  2, ED04, FSD
     N 24 ,      X 168.
```

PANEL

```
/
/       ******  OPERATION 1
/  CLECO, OR TACK RUN
/
/       @@@@@@@@@@@@@@@@@@@@@@
  OP=01,
ED01,  DD10, EGBR, ANGL=   3, RTZO, ST10, FSDP,  DM00,  FCMD, TACK, SCNO, FCMS,
     N 1 ,       X  13.750  Y   8.378  A 0.102  B-0.027  Z 7.948  #   10 ;
SCN1,
     N 2 ,       X  14.834  Y   8.512  A 0.101           Z 7.968  #   20 ;
SCN2,  CMS,
     N 2.1 ,     X  35.140  Y   9.469                    Z 6.494  #   30 ;
SCNO, FCMS,
     N 3 ,       X  35.139  Y   9.511                    Z 8.398  #   40 ;
SCN1,
     N 4 ,       X  36.139  Y   9.571                    Z 8.427  #   50 ;
     N 5 ,       X  37.226  Y   9.566                    Z 8.447  #   60 ;
SCN2,  CMS,
     N 5.1 ,     X  51.464  Y  10.311  A 0.102           Z 6.493  #   70 ;
ED04,   SCNO, FCMS,
     N 6 ,       X  51.461  Y  10.432                    Z 8.759  #   80 ;
     N 7 ,       X  52.496  Y  10.488  A 0.101           Z 8.769  #   90 ;
SCN1,
     N 8 ,       X  53.550  Y  10.567                    Z 8.789  #  100 ;
SCN2,  CMS,
     N 8.1 ,     X  77.306  Y  11.736  A 0.102           Z 6.493  #  110 ;
SCNO, FCMS,
     N 9 ,       X  77.422  Y  11.857                    Z 9.316  #  120 ;
     N 10 ,      X  78.398  Y  11.909  A 0.101           Z 9.326  #  130 ;
SCN1,
     N 11 ,      X  79.511  Y  11.969                    Z 9.345  #  140 ;
SCN2,  CMS,
     N 11 1 ,    X 107.571  Y  13.513                    Z 6.494  #  150 ;
SCNO, FCMS,
     N 12 ,      X 107.574  Y  13.499                    Z 9.951  #  160 ;
SCN1,
     N 13 ,      X 108.966  Y  13.575                    Z 9.980  #  170 ;
     N 14 ,      X 110.260  Y  13.639                   Z10.009  #  180 ;
SCN2,  CMS,
     N 14.1 ,    X 129.621  Y  14.654                    Z 6.494  #  190 ;
SCNO, FCMS,
     N 15 ,      X 129.618  Y  14.768                   Z10.429  #  200 ;
SCN1,
     N 16 ,      X 131.056  Y  14.839  A 0.102           Z10.458  #  210 ;
SCNO,
     N 17 ,      X 132.387  Y  14.914  A 0.100           Z10.479  #  220 ;
SCN2,  CMS,
     N 17.1 ,    X 162.289  Y  16.412  A 0.102           Z 6.493  #  230 ;
SCNO, FCMS,
     N 18 ,      X 162.443  Y  16.510                   Z11.132  #  240 ;
     N 19 ,      X 163.171  Y  16.543  A 0.101           Z11.142  #  250 ;
SCN1,
     N 20 ,      X 163.882  Y  16.585                   Z11.162  #  260 ;
SCN2,  CMS,
     N 20.1 ,    X 167.769  Y  15.491  A 0.122  B-0.028  Z 6.494  #  270 ;
EGTL,  ED03,  ANGL= 67, SCNO, FCMS,
     N 21 ,      X 167.759  Y  15.499                   Z11.386  #  280 ;
     N 22 ,      X 167.368  Y  14.599  A 0.137  B-0.029  Z11.495  #  290 ;
               CMD, SCN1,
     N 23 ,                                            Z 6.495  #  300 ;
ANGL=  2,  ED04,  FSDP,  DM00,  FCMD, SCNO,
     N 24 ,      X 168.132  Y  21.260  A 0.043  B-0.024  Z10.926  #  310 ;
```

Figure A-2 Master Coordinate Source File (Sheet 1 of 2)

```
/       @@@@@@@@@@@@@@@@@@@@
/
/       ******  OPERATION 2
/
/       @@@@@@@@@@@@@@@@@@@@
/
ED01, DD11, EGBR, ANGL= 3, HOLE, SCN0, FCMS,
  OP=02,
     N 278 ,    X  15.737  Y   8.476  A 0.101                  Z 7.988  # 3090 ;
 SCN3,
     N 279 ,    X  16.502  Y   8.545                           Z 7.998  # 3100 ;
     N 280 ,    X  17.374  Y   8.641                           Z 8.017  # 3110 ;
     N 281 ,    X  18.271  Y   8.682                           Z 8.037  # 3120 ;
     N 282 ,    X  19.160  Y   8.725                           Z 8.056  # 3130 ;
     N 283 ,    X  19.928  Y   8.765                           Z 8.076  # 3140 ;
     N 284 ,    X  20.802  Y   8.808                           Z 8.095  # 3150 ;
     N 285 ,    X  21.687  Y   8.851                           Z 8.115  # 3160 ;
     N 286 ,    X  22.573  Y   8.835  A 0.102                  Z 8.134  # 3170 ;
     N 287 ,    X  23.791  Y   8.958  A 0.101                  Z 8.154  # 3180 ;
     N 288 ,    X  25.022  Y   9.014                           Z 8.183  # 3190 ;
     N 289 ,    X  26.261  Y   9.075                           Z 8.213  # 3200 ;
     N 290 ,    X  27.533  Y   9.140                           Z 8.242  # 3210 ;
     N 291 ,    X  28.858                 A 0.102              Z 8.271  # 3220 ;
     N 292 ,    X  30.148  Y   9.261  A 0.101                  Z 8.291  # 3230 ;
     N 293 ,    X  31.388  Y   9.327                           Z 8.320  # 3240 ;
     N 294 ,    X  32.665  Y   9.391                           Z 8.349  # 3250 ;
     N 295 ,    X  33.948  Y   9.393  A 0.102                  Z 8.378  # 3260 ;
     N 296,     X  39.332  Y   9.652                           Z 8.486  # 3270 ;
     N 297 ,    X  40.498  Y   9.800  A 0.101                  Z 8.515  # 3280 ;
     N 298 ,    X  42.086  Y   9.899                           Z 8.554  # 3290 ;
     N 299 ,    X  43.805  Y   9.997                           Z 8.584  # 3300 ;
     N 300 ,    X  45.396  Y  10.024  A 0.102                  Z 8.622  # 3310 ;
 ST00,
     N 301 ,    X  46.968  Y  10.183  A 0.101                  Z 8.652  # 3320 ;
     N 302 ,    X  48.441  Y  10.265                           Z 8.681  # 3330 ;
 SCN2, CMS,
     N 302.1 ,  X  49.895  Y  10.300                           Z 6.494  # 3340 ;
 SCN0, FCMS, ST00,
     N 303 ,    X  49.858  Y  10.342                           Z 8.720  # 3350 ;
 ANGL=  2,
     N 304 ,    X  46.069  Y  15.465  A 0.060  B-0.025         Z 8.207  # 3360 ;
 SCN3,
     N 305 ,    X  44.059  Y  15.394  A 0.061                  Z 8.168  # 3370 ;
     N 306 ,    X  41.992  Y  15.324                           Z 8.119  # 3380 ;
     N 307 ,    X  39.851  Y  15.243                           Z 8.070  # 3390 ;
     N 308 ,    X  37.733  Y  15.173                           Z 8.021  # 3400 ;
     N 309 ,    X  36.193  Y  15.108                           Z 7.982  # 3410 ;
     N 310 ,    X  30.733  Y  14.904                           Z 7.865  # 3420 ;
     N 311 ,    X  28.983  Y  14.847                           Z 7.816  # 3430 ;
     N 312 ,    X  27.397  Y  14.790                           Z 7.787  # 3440 ;
     N 313 ,    X  25.688  Y  14.724                           Z 7.748  # 3450 ;
     N 314 ,    X  20.472  Y  14.509                           Z 7.631  # 3460 ;
     N 315 ,    X  19.481  Y  14.473                           Z 7.601  # 3470 ;
     N 316 ,    X  18.544  Y  14.432                           Z 7.582  # 3480 ;
     N 317 ,    X  17.600  Y  14.399                           Z 7.562  # 3490 ;
 SCN0,
     N 318 ,    X  16.668  Y  14.367                           Z 7.543  # 3500 ;
 ED07,  EGTL,
     N 319 ,    X  16.473  Y  15.234  A 0.055                  Z 7.476  # 3510 ;
 SCN3,
     N 320 ,    X  17.208  Y  15.264                           Z 7.495  # 3520 ;
     N 321 ,    X  18.559  Y  15.286                           Z 7.515  # 3530 ;
     N 322 ,    X  19.293  Y  15.326                           Z 7.534  # 3540 ;
     N 323 ,    X  20.1
       CHANGE EDGE DI
 SCN0, ED01,
     N 324 ,    X  21.6
 SCN3,
     N 325 ,    X  24.8
     N 326 ,    X  26.6
     N 327 ,    X  28.3
 SCN0,
     N 328 ,    X  30.0
 ED07,
     N 329 ,    X  31.8
  ED05,
     N 330 ,    X  35.6
  SCN3,
     N 331 ,    X  37.5
     N 332 ,    X  39.3
     N 333 ,    X  41.3
     N 334 ,    X  43.0
     N 335 ,    X  45.2
     N 336 ,    X  47.2
  SCN2, CMS,
     N 336.1 ,  X  51.1
  SCN0, FCMS, ST00,
     N 337 ,
  SCN2, CMS,
     N 337.1 ,  X  68.2
  ED01, FCMS,   EGBR, AN
     N 338 ,    X  69.2
  SCN3,
     N 339 ,    X  66.9
  SCN0,
     N 340 ,    X  65.5
  SCN1,
     N 341 ,    X  64.2
  SCN0,
     N 342 ,    X  59.2
  SCN3,
     N 343 ,    X  58.1
     N 344 ,    X  56.8
  SCN0,
     N 345 ,    X  55.5
     N 346 ,    X  54.2
  SCN3,
     N 347 ,    X  53.0
     N 348 ,    X  51.8
     N 349 ,    X  50.6
     N 350 ,    X  49.5
     N 351 ,    X  48.5
     N 352 ,    X  47.5
  SCN0,
     N 353 ,    X  46.4
  ED01,  ANGL=  0,
     N 354 ,    X  55.7
  SCN3,
     N 355 ,    X  53.8
     N 356 ,    X  47.9
     N 357 ,    X  46.0
     N 358 ,    X  44.0
     N 359 ,    X  42.1
     N 360 ,    X  40.8
  SCN0,
     N 361 ,    X  39.7
     N 362 ,    X  36.1
END
```

```
    N 323 ,    X  20.109  Y  15.353                          Z 7.554  # 3550 ;
       CHANGE EDGE DISTANCE DUE TO DOUBLER
SCN0, ED01,
    N 324 ,    X  21.679  Y  15.428                          Z 7.593  # 3560 ;
SCN3,
    N 325 ,    X  24.861  Y  15.548                          Z 7.671  # 3570 ;
    N 326 ,    X  26.615  Y  15.616                          Z 7.710  # 3580 ;
    N 327 ,    X  28.332  Y  15.677                          Z 7.739  # 3590 ;
SCN0,
    N 328 ,    X  30.036  Y  15.734                          Z 7.779  # 3600 ;
ED07,
    N 329 ,    X  31.896  Y  15.807                          Z 7.827  # 3610 ;
 ED05,
    N 330 ,    X  35.659  Y  16.014  A 0.054                 Z 7.915  # 3620 ;
 SCN3,
    N 331 ,    X  37.550  Y  16.022  A 0.055                 Z 7.964  # 3630 ;
    N 332 ,    X  39.344  Y  16.092                          Z 8.003  # 3640 ;
    N 333 ,    X  41.341  Y  16.182  A 0.054                 Z 8.052  # 3650 ;
    N 334 ,    X  43.308  Y  16.313                          Z 8.091  # 3660 ;
    N 335 ,    X  45.299  Y  16.386                          Z 8.140  # 3670 ;
    N 336 ,    X  47.267  Y  16.470                          Z 8.179  # 3680 ;
 SCN2, CMS,
    N 336.1 ,  X  51.172  Y  16.593                          Z 6.499  # 3690 ;
 SCN0, FCMS, ST00,
    N 337 ,               Y  16.601                          Z 8.267  # 3700 ;
 SCN2, CMS,
    N 337.1 ,  X  68.276  Y  21.995  A 0.023  B-0.024       Z 6.495  # 3710 ;
 ED01, FCMS,   EGBR, ANGL=  1, SCN0, ST00,
    N 338 ,    X  68.277  Y  22.028                          Z 8.487  # 3720 ;
 SCN3,
    N 339 ,    X  66.953  Y  22.004                          Z 8.458  # 3730 ;
 SCN0,
    N 340 ,    X  65.549  Y  21.978                          Z 8.419  # 3740 ;
 SCN1,
    N 341 ,    X  64.251  Y  21.944                          Z 8.389  # 3750 ;
 SCN0,
    N 342 ,    X  59.297  Y  21.862  A 0.024                 Z 8.272  # 3760 ;
 SCN3,
    N 343 ,    X  58.100  Y  21.841                          Z 8.243  # 3770 ;
    N 344 ,    X  56.850  Y  21.734                          Z 8.213  # 3780 ;
 SCN0,
    N 345 ,    X  55.544  Y  21.787                          Z 8.184  # 3790 ;
    N 346 ,    X  54.268  Y  21.765                          Z 8.155  # 3800 ;
 SCN3,
    N 347 ,    X  53.024  Y  21.743                          Z 8.126  # 3810 ;
    N 348 ,    X  51.800  Y  21.710                          Z 8.096  # 3820 ;
    N 349 ,    X  50.606  Y  21.603                          Z 8.067  # 3830 ;
    N 350 ,    X  49.565  Y  21.647                          Z 8.038  # 3840 ;
    N 351 ,    X  48.535  Y  21.616                          Z 8.018  # 3850 ;
    N 352 ,    X  47.501  Y  21.594                          Z 7.989  # 3860 ;
 SCN0,
    N 353 ,    X  46.455  Y  21.576                          Z 7.969  # 3870 ;
 ED01,  ANGL=  0,
    N 354 ,    X  55.771  Y  27.723  A-0.005                 Z 8.136  # 3880 ;
 SCN3,
    N 355 ,    X  53.806  Y  27.718                          Z 8.088  # 3890 ;
    N 356 ,    X  47.977  Y  27.699                          Z 7.951  # 3900 ;
    N 357 ,    X  46.025  Y  27.691                          Z 7.902  # 3910 ;
    N 358 ,    X  44.048  Y  27.695                          Z 7.853  # 3920 ;
    N 359 ,    X  42.148  Y  27.655                          Z 7.814  # 3930 ;
    N 360 ,    X  40.852  Y  27.701                          Z 7.785  # 3940 ;
 SCN0,
    N 361 ,    X  39.708  Y  27.690                          Z 7.756  # 3950 ;
    N 362 ,    X  36.189  Y  27.691                          Z 7.697  # 3960 ;
END
```

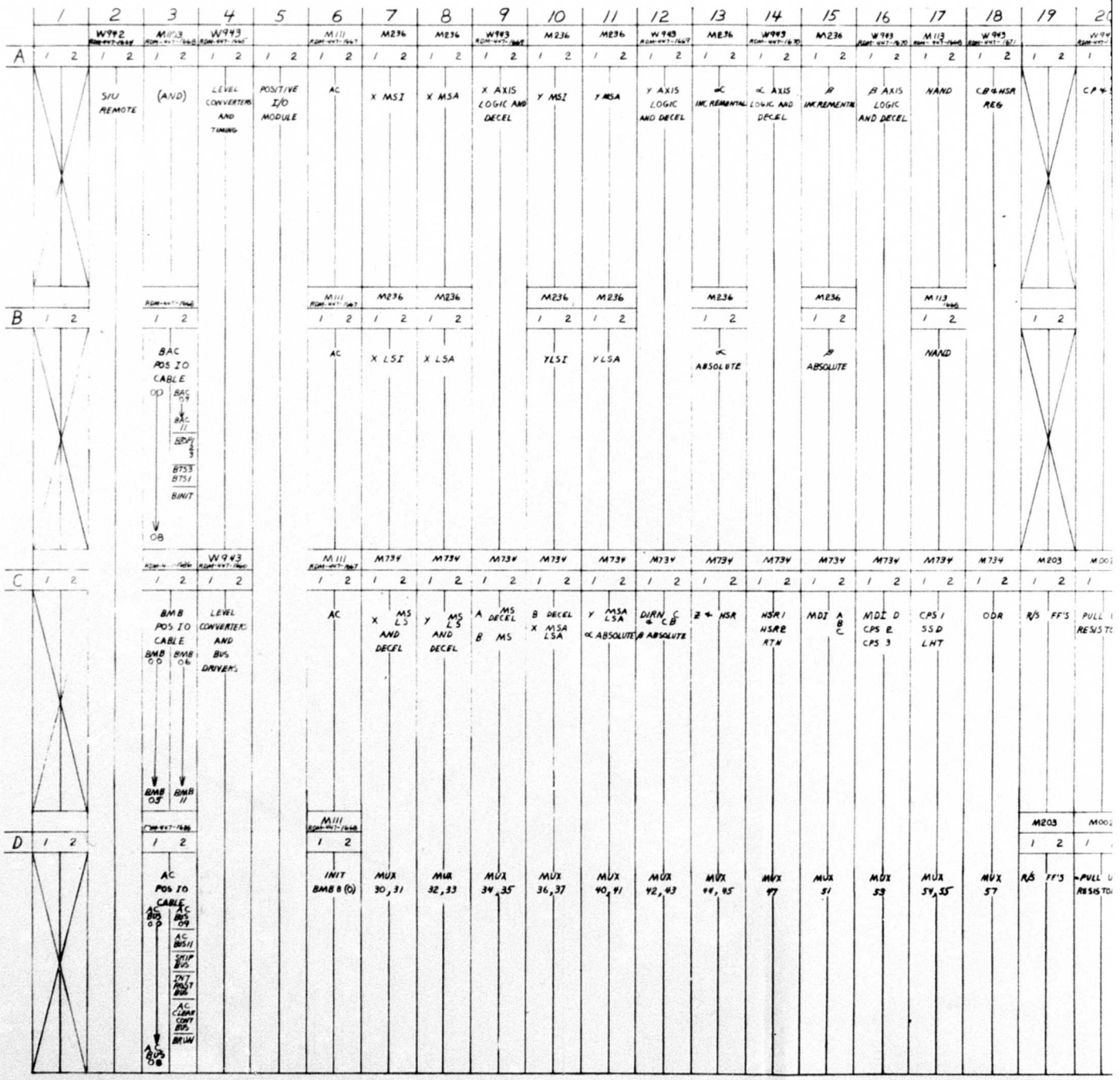
Figure A-2 Master Coordinate Source File (Sheet 2 of 2)

APPENDIX B

ELECTRICAL DRAWINGS FOR

MULTIUSER SYSTEM

★ U. S. GOVERNMENT PRINTING OFFICE: 1977 — 757-001/344


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
A
W992
S/U REMOTE
(AND)
W993
LEVEL CONVERTERS AND TIMING
POSITIVE I/O MODULE
AC
X MSI
X MSA
X AXIS LOGIC AND DECEL
Y MSI
Y MSA
Y AXIS LOGIC AND DECEL
∝ INCREMENTAL
∝ AXIS LOGIC AND DECEL
β INCREMENTAL
β AXIS LOGIC AND DECEL
NAND
C.P. & NSR REG
B
BAC POS IO CABLE
OD
OB
AC
X LSI
X LSA
YLSI
YLSA
∝ ABSOLUTE
β ABSOLUTE
NAND
C
BMB POS IO CABLE
BMB 00
BMB 06
BMB 05
BMB 11
LEVEL CONVERTERS AND BUS DRIVERS
AC
X MS LS AND DECEL
Y MS LS AND DECEL
A DECEL MS
B MS
B DECEL
X MSA LSA
Y MSA LSA
∝ ABSOLUTE
DIRN C ∝ C β ABSOLUTE
Z ∝ NSR
NSR1 NSR2 RTN
MDI A B C
MDI D CPS 2 CPS 3
CPS 1 SSD LNT
ODR
R/S
FF'S
PULL
RESISTO
D
AC POS IO CABLE
AC BUS 00
AC BUS 09
AC BUS 11
SKIP BUS
INT MAST BUS
AC CLAMP CONT BUS
BRUN
AC BUS 08
INIT BMB 8 (0)
MUX 30, 31
MUX 32, 33
MUX 34, 35
MUX 36, 37
MUX 40, 41
MUX 42, 43
MUX 44, 45
MUX 47
MUX 51
MUX 53
MUX 54, 55
MUX 57
R/S
FF'S
PULL
RESISTO

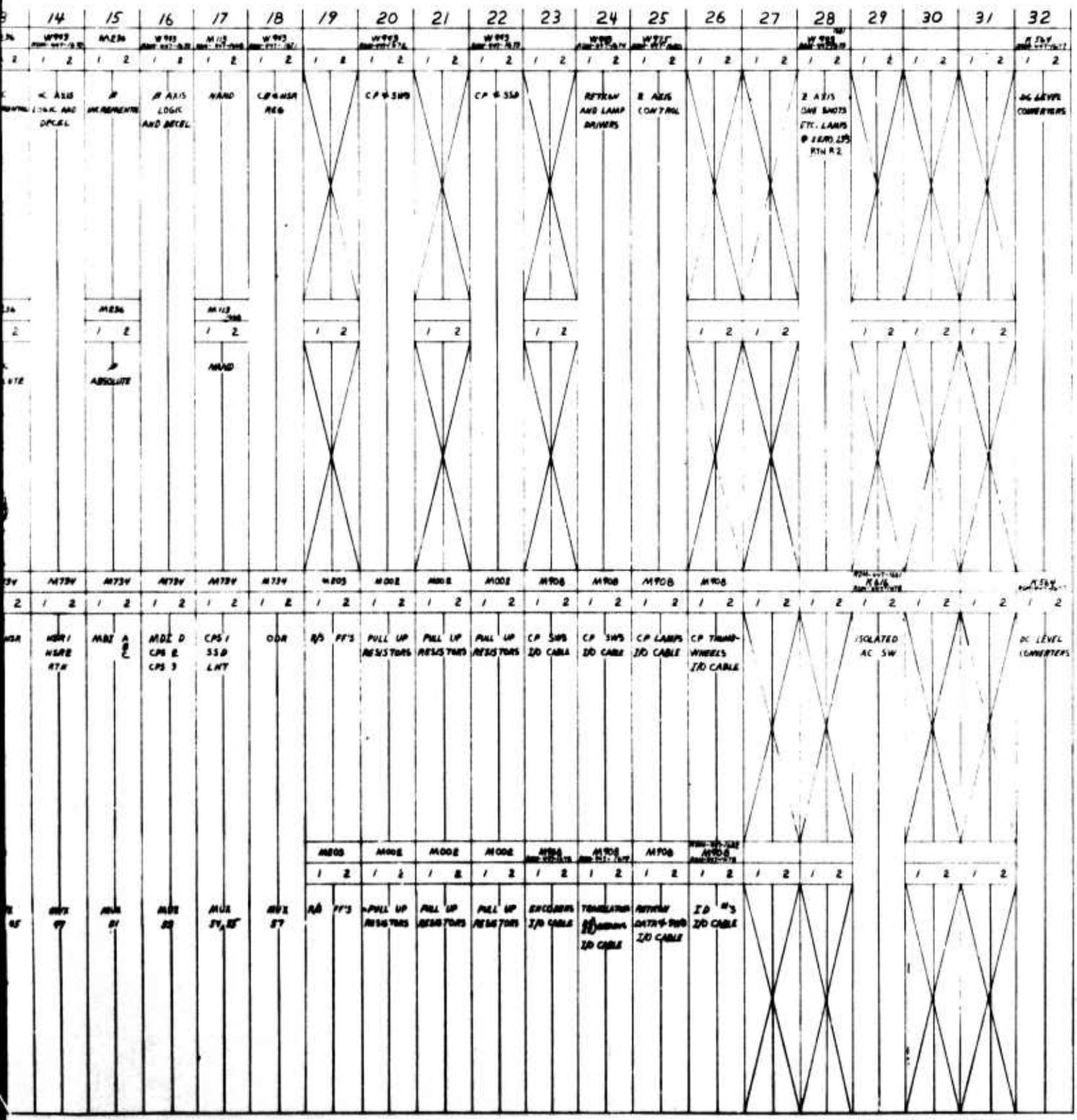
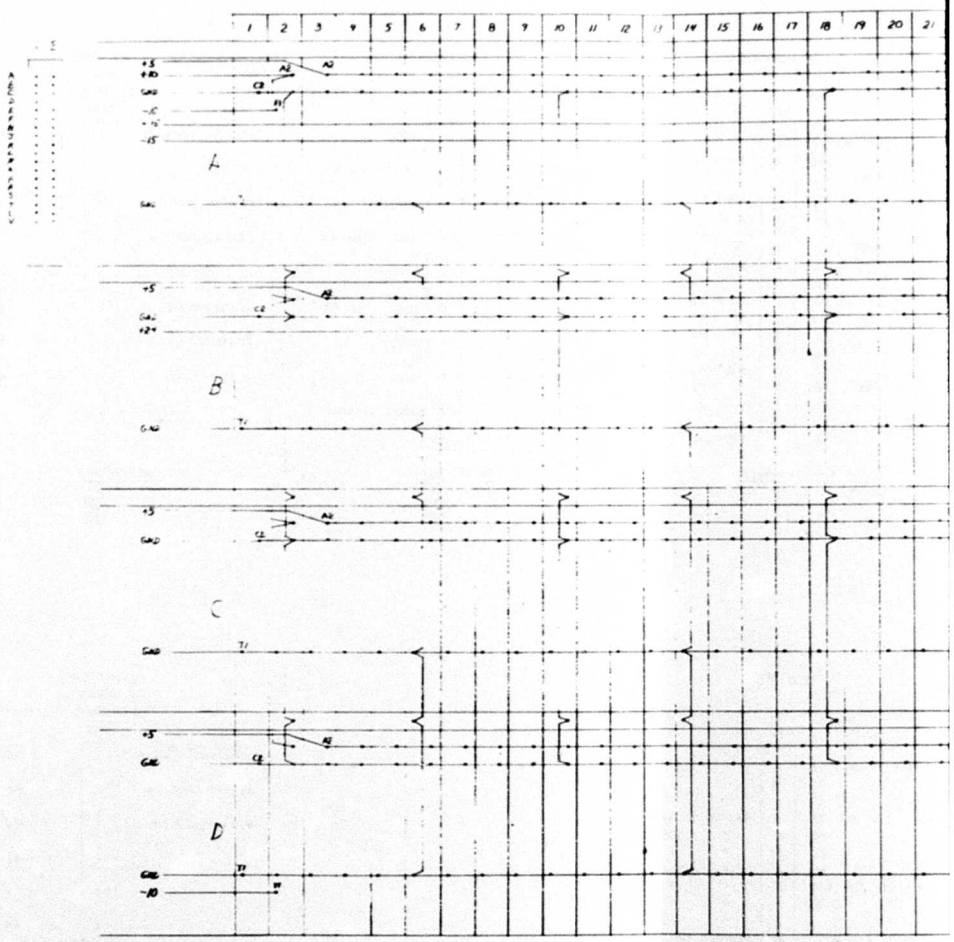


Figure B-1. Module Utilization

BEST AVAILABLE COPY



28 $_{30}$ WIRE WRAP

A02A2 }
A01B2 } +10 VDC
A01A2 }

A25B2 }
A01B2 } +15 VDC
A02B2 }

A25A2 }
A25B2 } -15 VDC
A02B2 }

A21B2 }
A01A2 }
A02A2 } +24VDC
A01B2 }
A02B2 }

72 CA BUS

A25A2 }
A25B2 } +24 VDC
C25B2 }

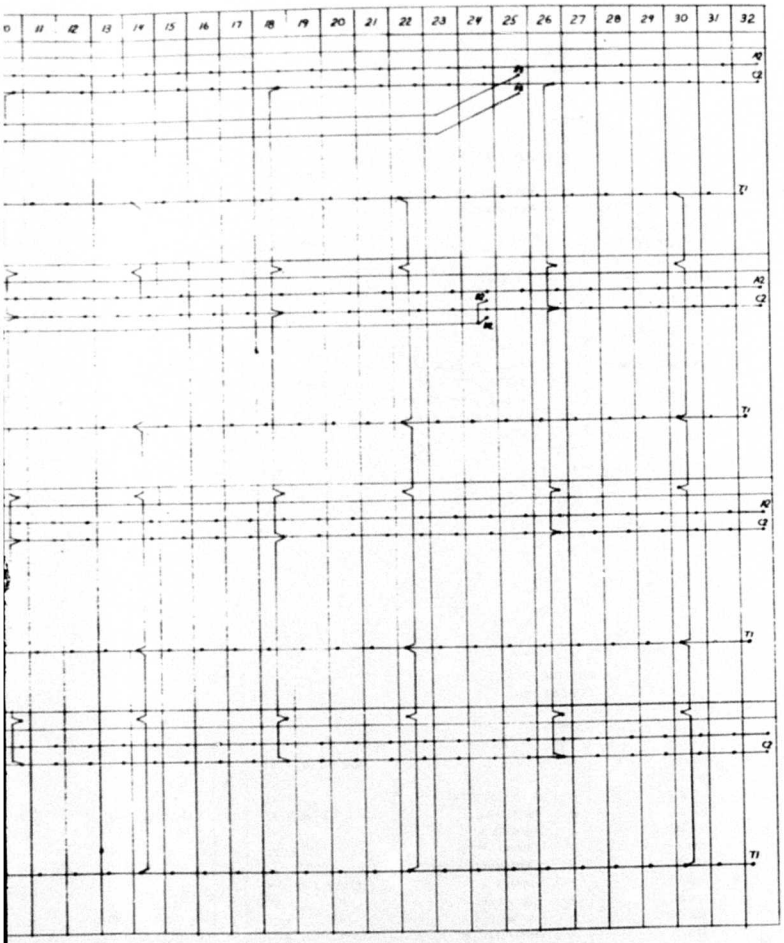


Figure B-2. Power Bus Wiring — Machine Backplane

CONTROL FUNCTIONS

C23

+Y, BETA L	A	1		
-Y, BETA L	B	2	SLASH DELETE H	
+X ALPHA L	C	3		
-X, ALPHA L	D	4	SKIP HOLE L	
CYCLE START L	E	5	SKIP HOLE H	
CYCLE START H	F	6	SINGLE CYCLE L	
CYCLE STOP L	H	7	SINGLE CYCLE H	
CYCLE STOP H	J	8	PUNCH HOLE L	
CONTINUE L	K	9	CLOCO HOLE L	
CONTINUE H	L	10	AUTO L	
DATA LOAD L	M	11	MANUAL L	
DATA LOAD H	N	12	MOLES L	
RET TO ZERO L	P	13	OPERATION L	
RET TO ZERO H	R	14	SCAN L	
DISPLAY ADST L	S	15	DRILL L	
SIG GND	T	16	X L	
DISPLAY ADST H	U	17	ALPHA L	
SLASH DELETE L	V	18	Y L	

REF RDM-447- /661 /670 /672 /675

MDI'S

C29

BETA L	A	1		
CHECK ZERO L	B	2	DISPLAY READY DISABLE GND	
SPARE	C	3		
Z EXTEND L	D	4	DISPLAY BACK SPACE O.S.L	
Z EXTEND H	E	5	CHECK ZERO H	
Z RETRACT L	F	6	SPARE	
Z RETRACT H	H	7	"	
SPARE SW L	J	8	"	
SPARE SW H	K	9	"	
DISPLAY BINARY 32H	L	10	SPARE	
" 16H	M	11		
" 8H	N	12		
" 4H	P	13		
" 2H	R	14		
" 1H	S	15		
SIGNAL GND	T	16		
DISPLAY DATA MDB 0.S.L	U	17		
" CLEAR L	V	18		

REF RDM-447- /661 /669 /673 /675 /681

LAMPS M908

C25

+24 VDC	A	1		
+24 VDC	B	2	MDB E BIT 2L	
+24 GND	C	3		
+24 GND	D	4	MDB E BIT 1L	
EMETO STOP 24 (BRAKE)	E	5	MDB A BIT 8L	
CYCLE START 24	F	6	4L	
CYCLE STOP 24	H	7	2L	
RET. TO ZERO 24	J	8	1L	
ENTER DATA 24	K	9	B BIT 8L	
CPU READY 24	L	10	4L	
CHECK ZERO 24	M	11	2L	
SPARE(FOR SW) 24	N	12	1L	
SPARE	P	13	SPARE	
SPARE 24(NO SW)	R	14	SHIELDS-TO CHASSIS GND.	
SPARE	S	15	CAMERA ROTATE 24	
SIG GND	T	16	CAMERA LAMPS ON 24	
MDB E BIT 8L	U	17	X AXIS OVERRIDE 24	
4L	V	18		

REF RDM-447- /661 /680 /690 /694 /695 /696 /698

THUMBWHEELS

C26

MDI SW +L	A	1		
-L	B	2	D BIT 1L	
A BIT 8L	C	3		
4L	D	4	E BIT 8L	
2L	E	5	4L	
1L	F	6	2L	
B BIT 8L	H	7	1L	
4L	J	8	MDI SW +L	
2L	K	9	-L	
1L	L	10	A BIT 8L	
C BIT 8L	M	11	4L	
4L	N	12	2L	
2L	P	13	1L	
1L	R	14	B BIT 8L	
D BIT 8L	S	15	4L	
4L	T	16	2L	
2L	U	17	1L	
1L	V	18	C BIT 8L	

REF RDM-447-/661/669

ENCODERS

D23

	A	1		
	B	2		
+X	C	3	GND	
-X	D	4	+24 ON	
	E	5	RETRON LAMPS H	
	F	6	DRILL H	
+Y	H	7	Z AXIS POT SLAVE	
-Y	J	8		
	K	9		
	L	10		
ALPHA A	M	11		
ALPHA B	N	12		
	P	13		
	R	14		
BETA A	S	15		
	T	16		
BETA B	U	17		
	V	18		

REF RDM-447- /661 /669 /670 /678 /679 /681

TRANSLATORS

D24

	A	1		
	B	2		
	C	3	SHIELD	
X CLOCK	D	4	DATA BUS	
X FWD./REV.	E	5	DATA BUS	
	F	6		
Y CLOCK	H	7		
Y FWD./REV	J	8		
	K	9		
A CLOCK	L	10		
A FWD./REV.	M	11		
	N	12		
B CLOCK	P	13		
B FWD/REV.	R	14		
AT ZERO H	S	15		
SIG. GND.	T	16		
	U	17		
	V	18		

REF. RDM-447- /661 /669 /670 /679

RETRON CAMERA

D25

(4) HTR	A	1		
(10) D 0	B	2		
(9) D 1	C	3	GND (8) (9)(L)	
(20) D2	D	4	PWR ON L	
(11) D3	E	5	PWR ON H	
(21) D4	F	6	CAMERA ROT L	
(22) D5	H	7	CAMERA ROT H	
(12) D6	J	8	LAMPS L	
(23) D7	K	9	LAMPS H	
(24) D8	L	10	INITIALIZE L	
(25) D9	M	11	INITIALIZE H	
(26) D10	N	12	TEST L	
(27) D11	P	13	NORMAL L	
(7) LT	R	14	X AXIS OVERRIDE L	
(34) CLEAR (BLK)	S	15	X AXIS OVERRIDE H	
(16) (GRN) DIRECTION DATA	T	16	RAMP DOWN MO-X	
(3) CEP (BLK)	U	17	RAMP DOWN MO-Y	
	V	18	GND	

REF RDM-447- /661 /675 /690 /698

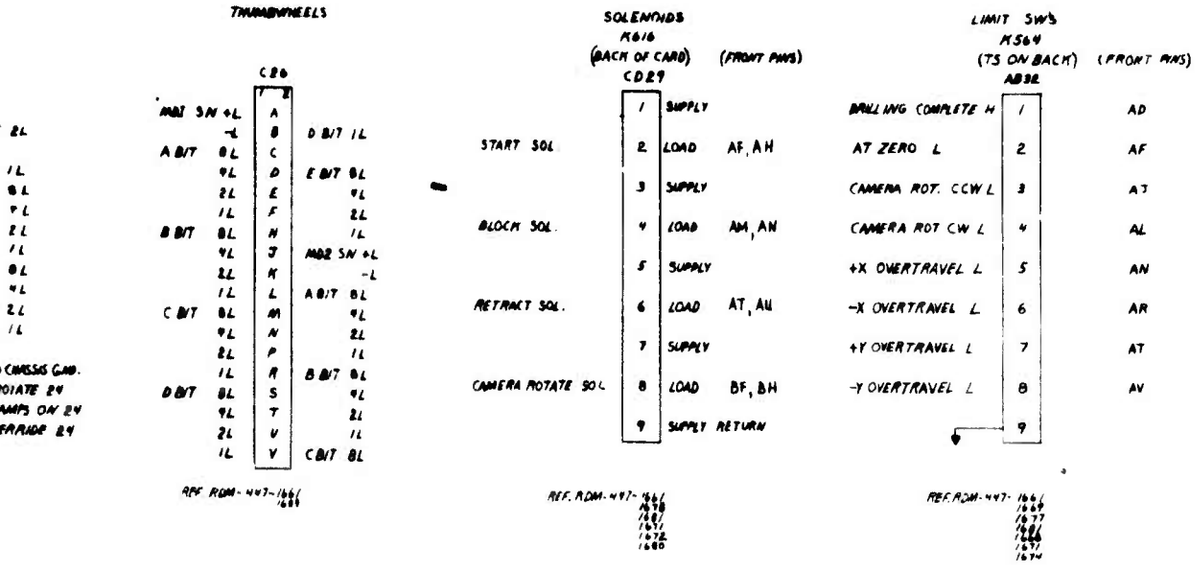
( ) = PIN NO'S AT RETRON CONTROLLER

I.D. #'S

D26

MDB C BIT 4L	A	1		
2L	B	2		
1L	C	3		
D BIT 8L	D	4	GANTRY ID GND	
4L	E	5	" 0(MS)	
2L	F	6	" 1	
1L	H	7	" 2	
FIXTURE ID GND	J	8	" 3	
" 0 (MS)	K	9	" 4	
" 1	L	10	" 5(LS)	
" 2	M	11	HEAD ID GND	
" 3	N	12	" 0(MS) N C	
" 4	P	13	" 1 (A BIT 3)	
" 5(LS)	R	14	" 2 (A BIT 2)	
	S	15	3 (A BIT 1)	
	T	16		
	U	17		
	V	18		

REF RDM-447- /661 /669 /670 /682 /689



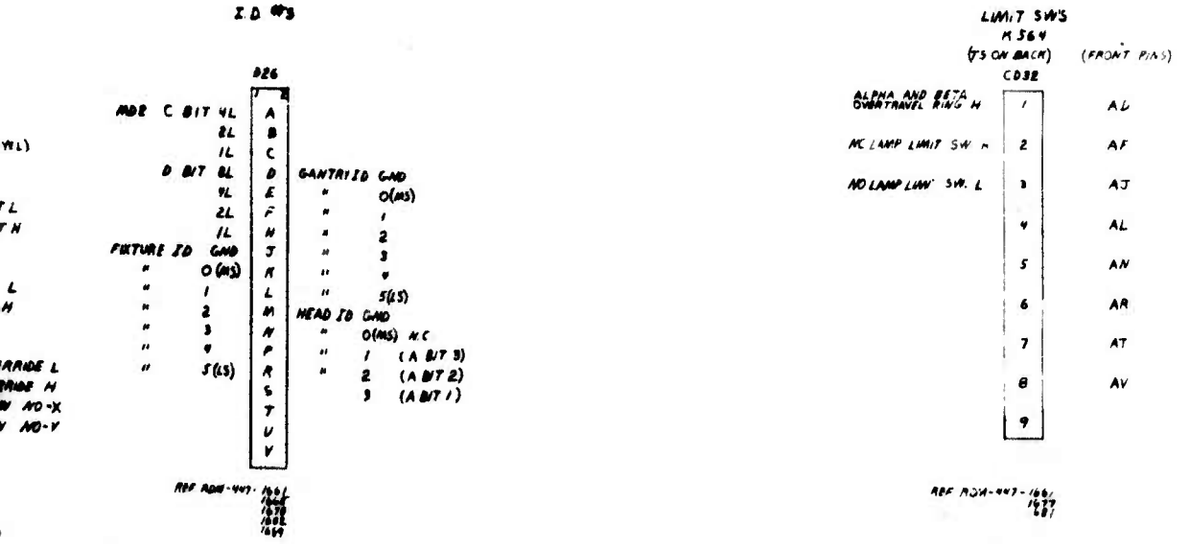
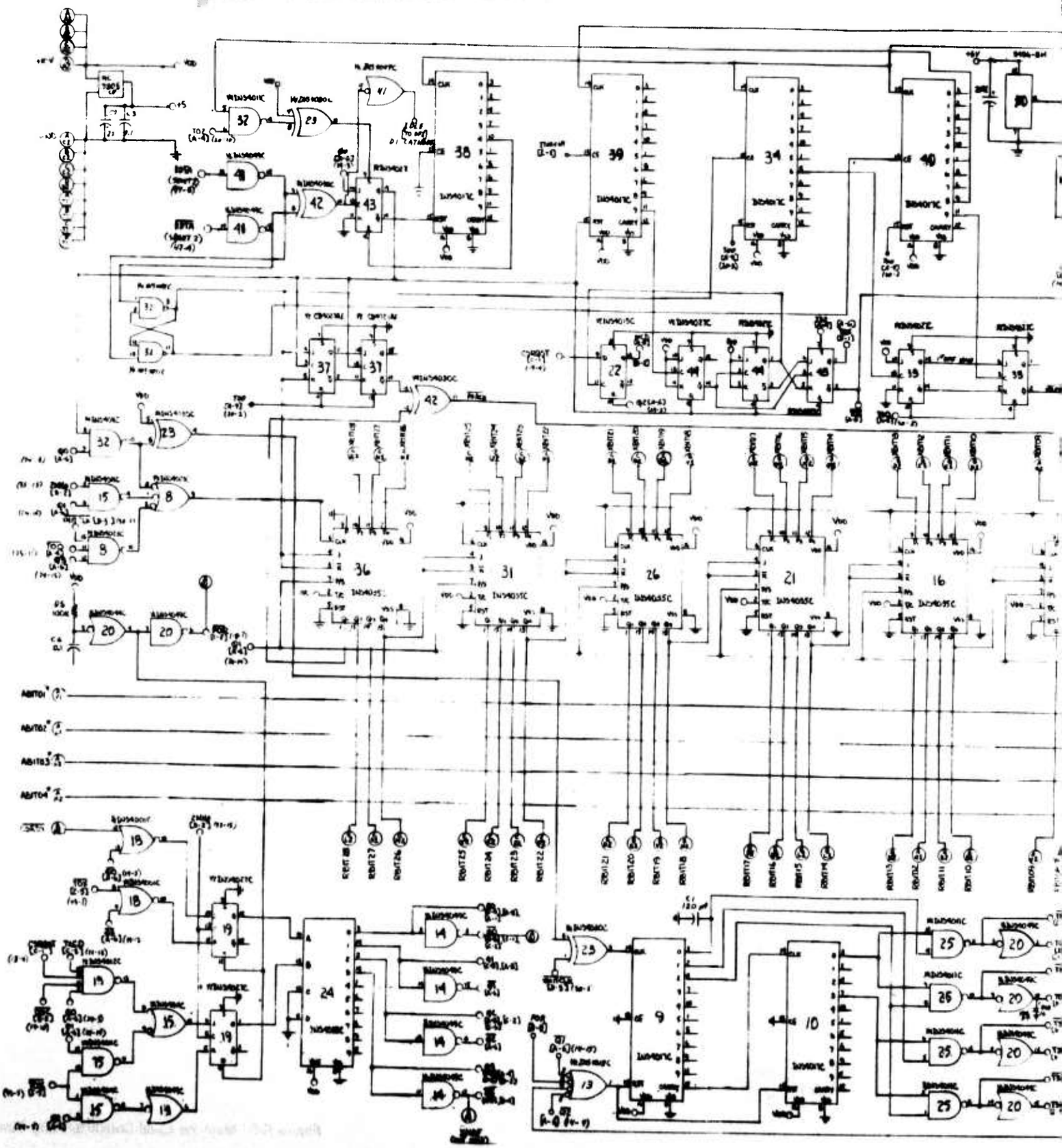


Figure B-3. Machine I/O – Connector Blocks

2

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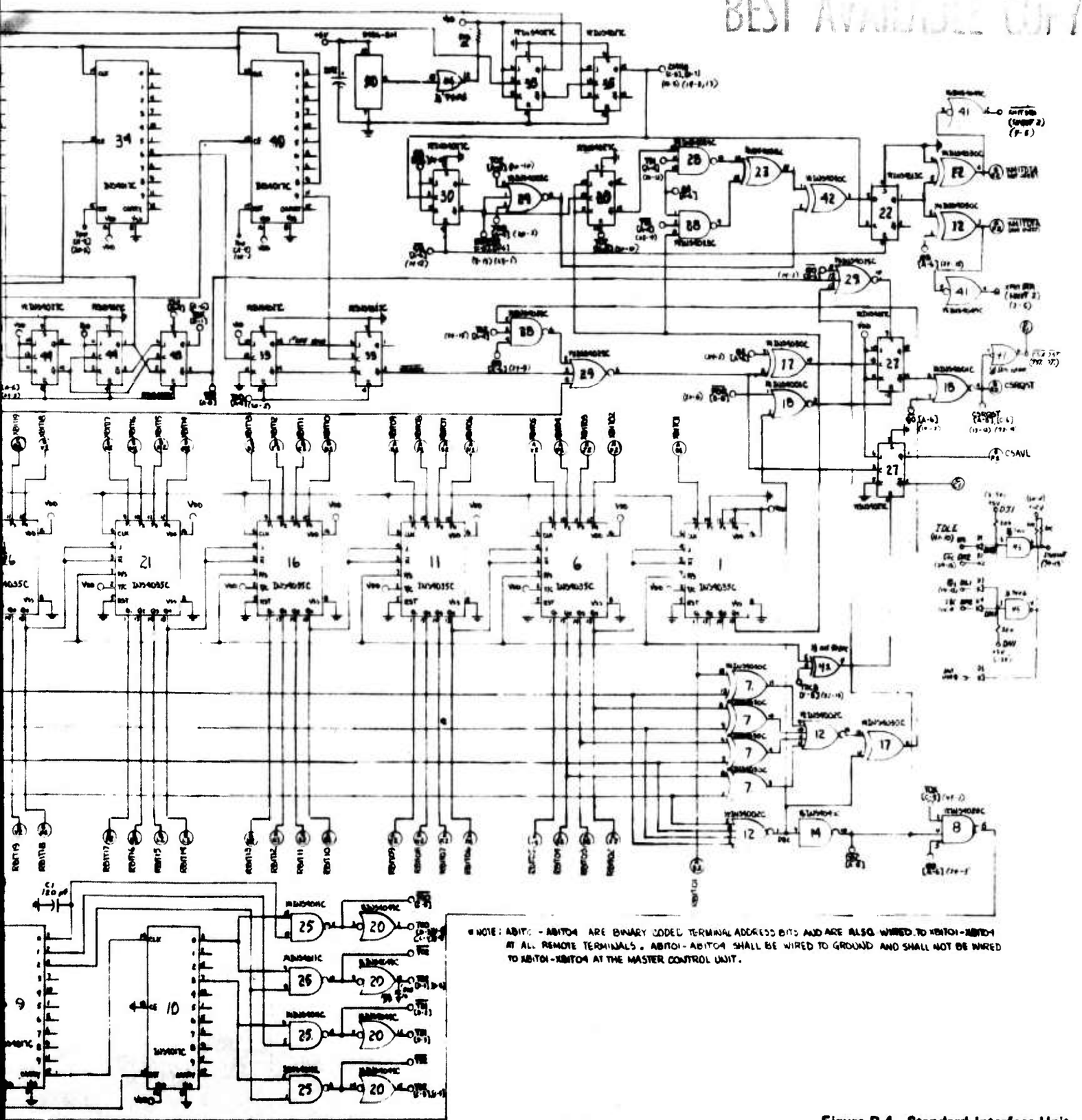
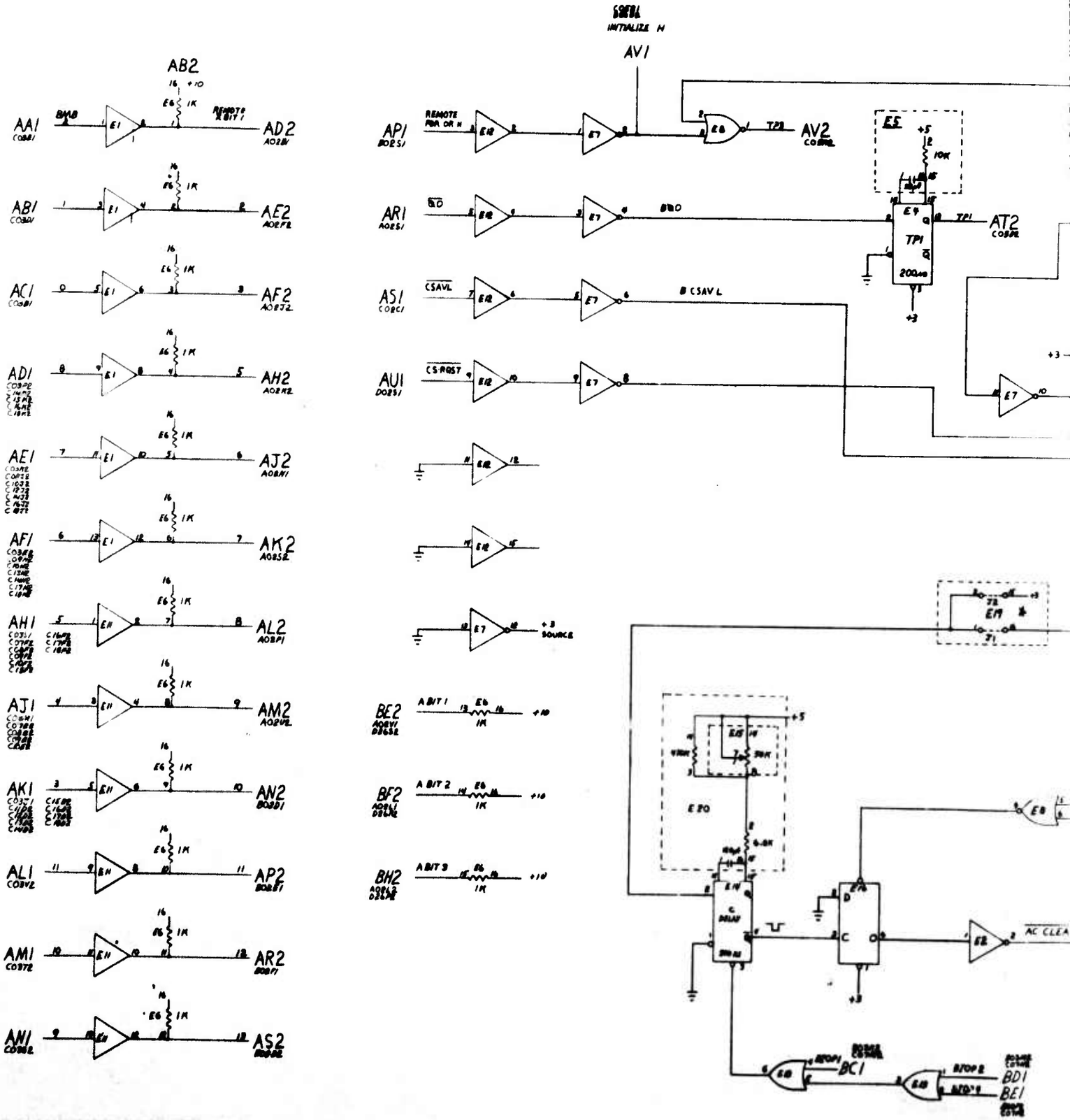
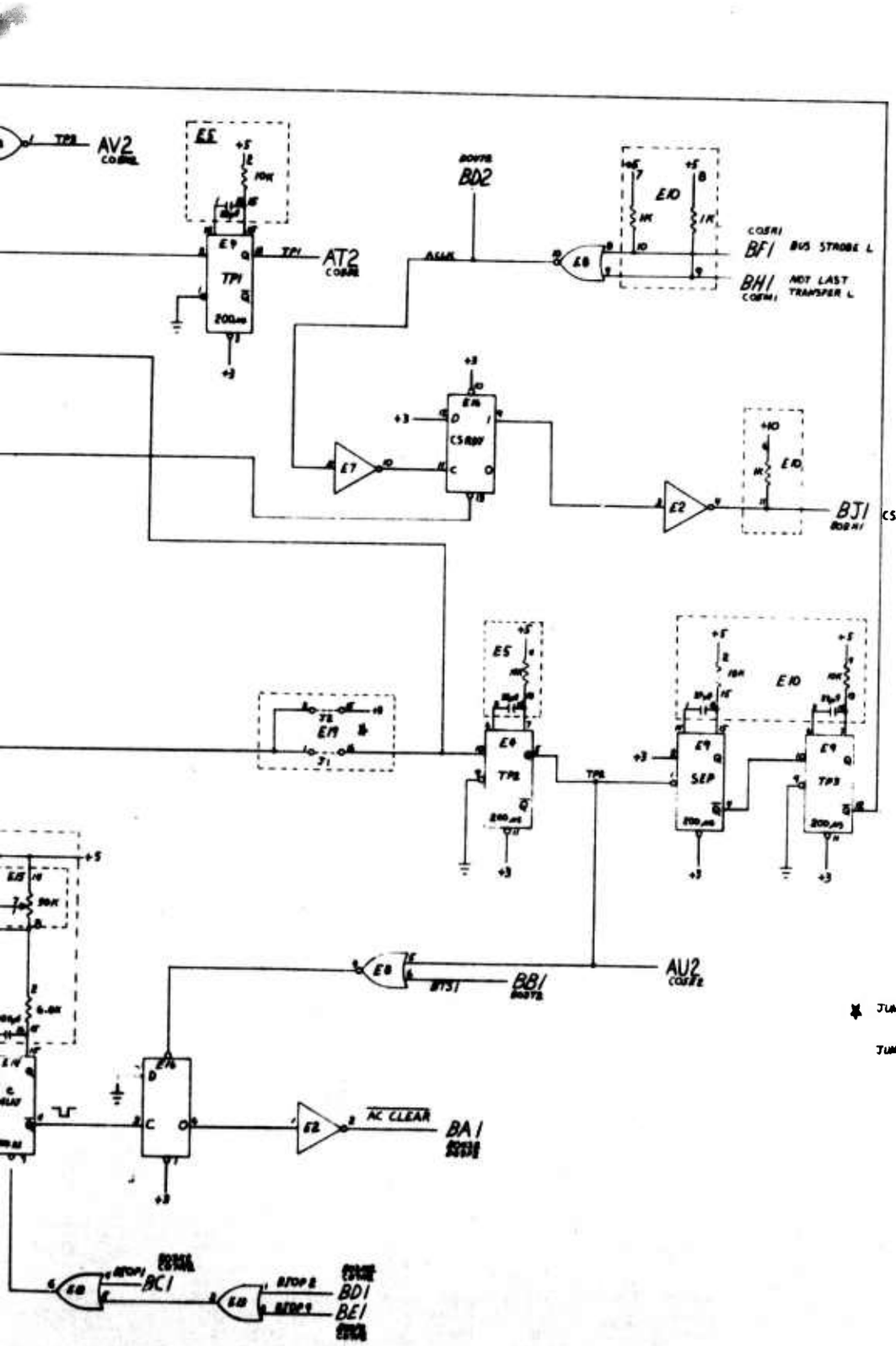


Figure B-4. Standard Interface Unit


AB2
AA1
AD2
AB1
AE2
AC1
AF2
AD1
AH2
AE1
AJ2
AF1
AK2
AH1
AL2
AJ1
AM2
AK1
AN2
AL1
AP2
AM1
AR2
AN1
AS2
AV1
AP1
AV2
AR1
AT2
AS1
AU1
BE2
BF2
BH2
TP1
200ms
BC1
BD1
BE1
AC CLEA



REF.	DESCRIPTION
E12	CPU80DAE
E8	N7400A
E7	N7404A
E2	N7406A
E1, 11	N7407A
E16	N7474A
E13	N7432A
E9, 9, 14	N74123B
E6	9ALC10R1KPAE 1K RES
E15	3099P-1-103 50K POT

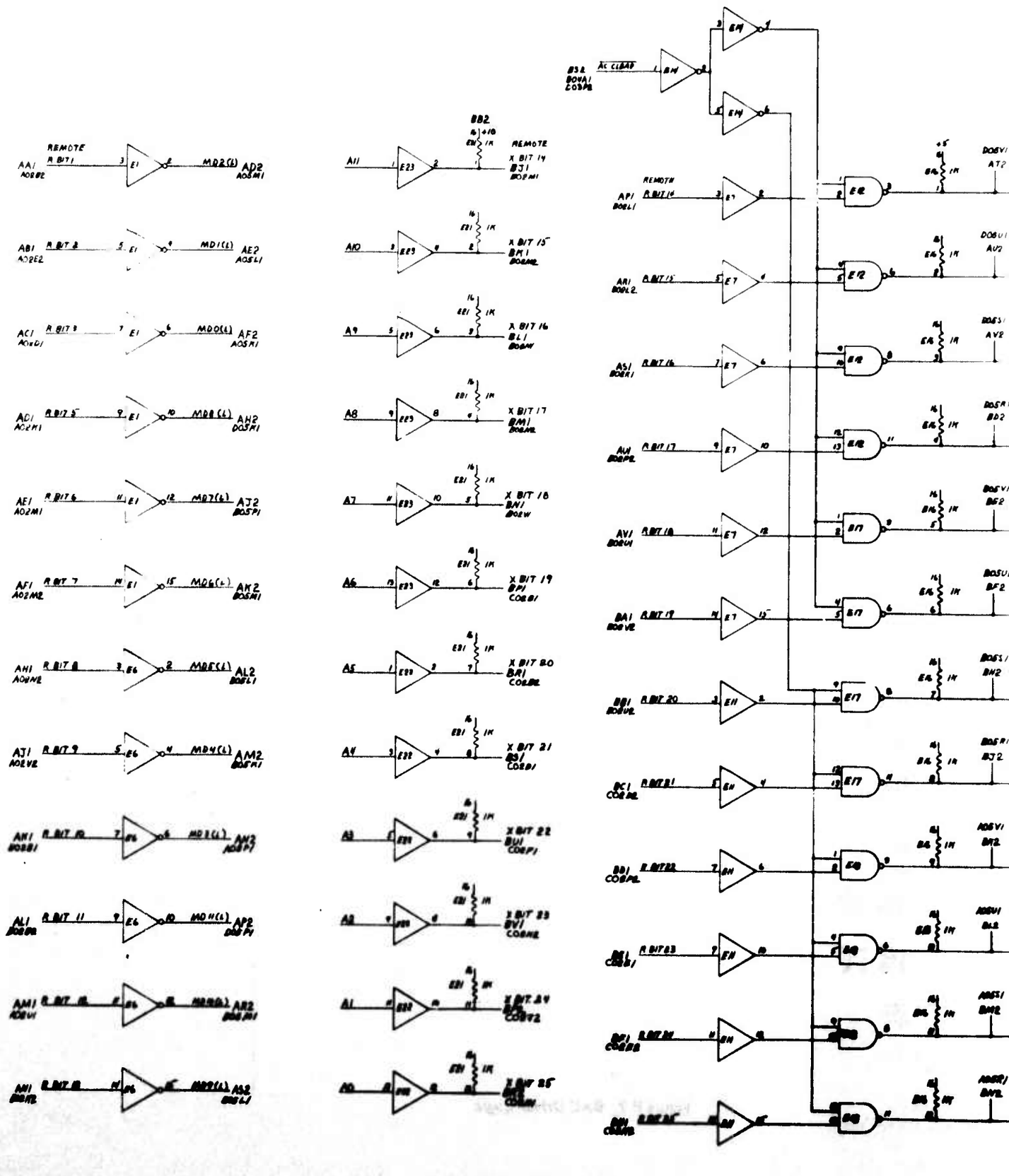
* JUMPER J1 INSTALLED WHEN POS I/O IS IN REMOTE UNIT

JUMPER J2 INSTALLED WHEN POS I/O IS IN CPU

SLOT ABCH

TYPE WW3

Figure B-5. Machine Level Converters and Timing


REMOTE
R BIT 1
MD2(L)
AD2
R BIT 2
MD1(L)
AE2
R BIT 3
MD0(L)
AF2
R BIT 5
MD8(L)
AH2
R BIT 6
MD7(L)
AJ2
R BIT 7
MD6(L)
AK2
R BIT 8
MD5(L)
AL2
R BIT 9
MD4(L)
AM2
R BIT 10
MD3(L)
R BIT 11
MD2(L)
R BIT 12
MD1(L)
R BIT 13
MD0(L)
REMOTE
X BIT 14
X BIT 15
X BIT 16
X BIT 17
X BIT 18
X BIT 19
X BIT 20
X BIT 21
X BIT 22
X BIT 23
X BIT 24
X BIT 25
AC CLEAR
REMOTE
R BIT 14
R BIT 15
R BIT 16
R BIT 17
R BIT 18
R BIT 19
R BIT 20
R BIT 21
R BIT 22
R BIT 23
R BIT 24
R BIT 25

REF.	DESCRIPTION
E1, 6	CD 9069 AE
E3, 11	CD 4050 AE
E16, 17, 18	N 7403 A
E14	N 7404 A
E22, 23	N 7417 A
E8, 13, 19	N 74175 B
E16, 21	9316 CIO2 XSPE

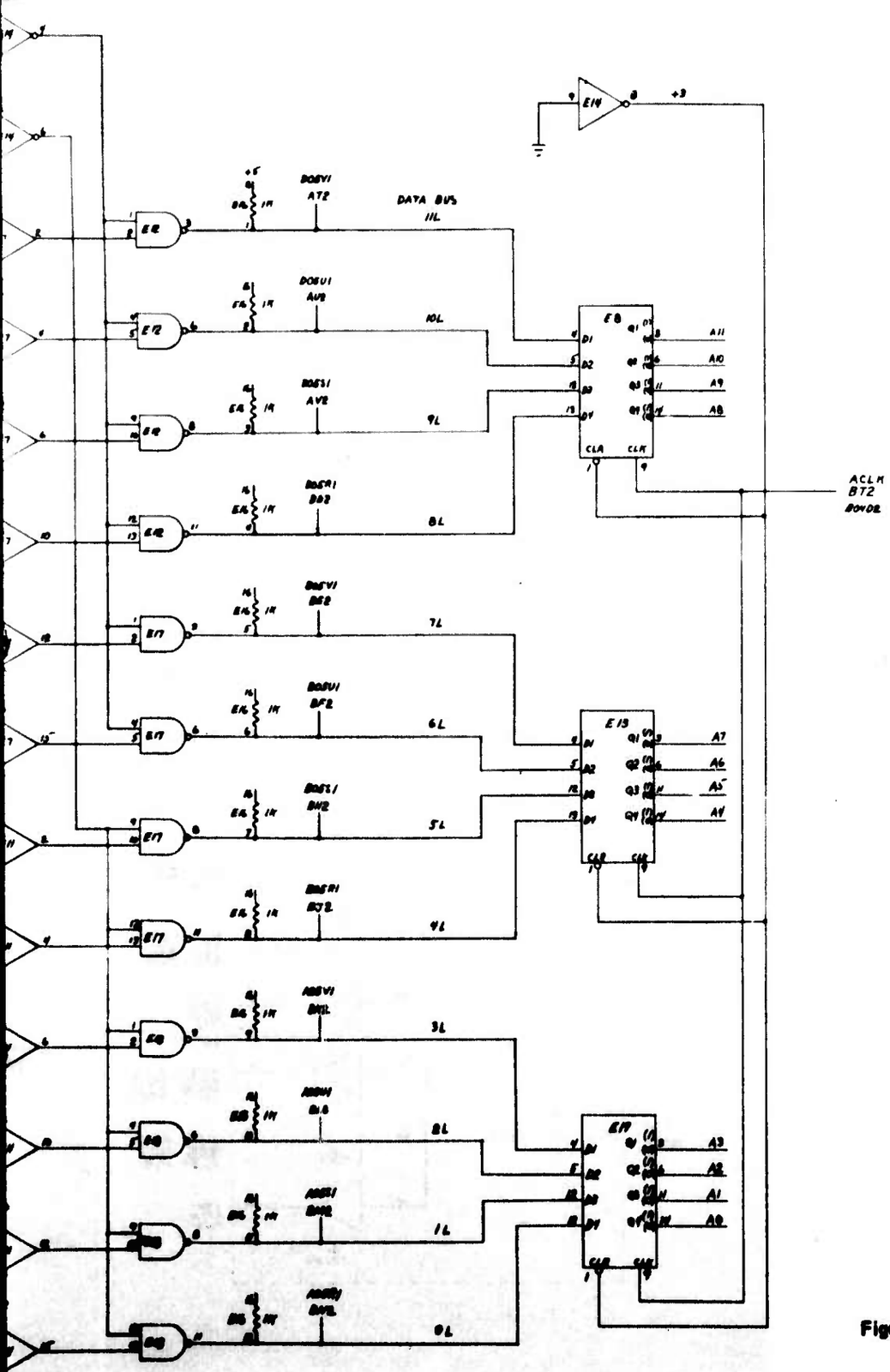
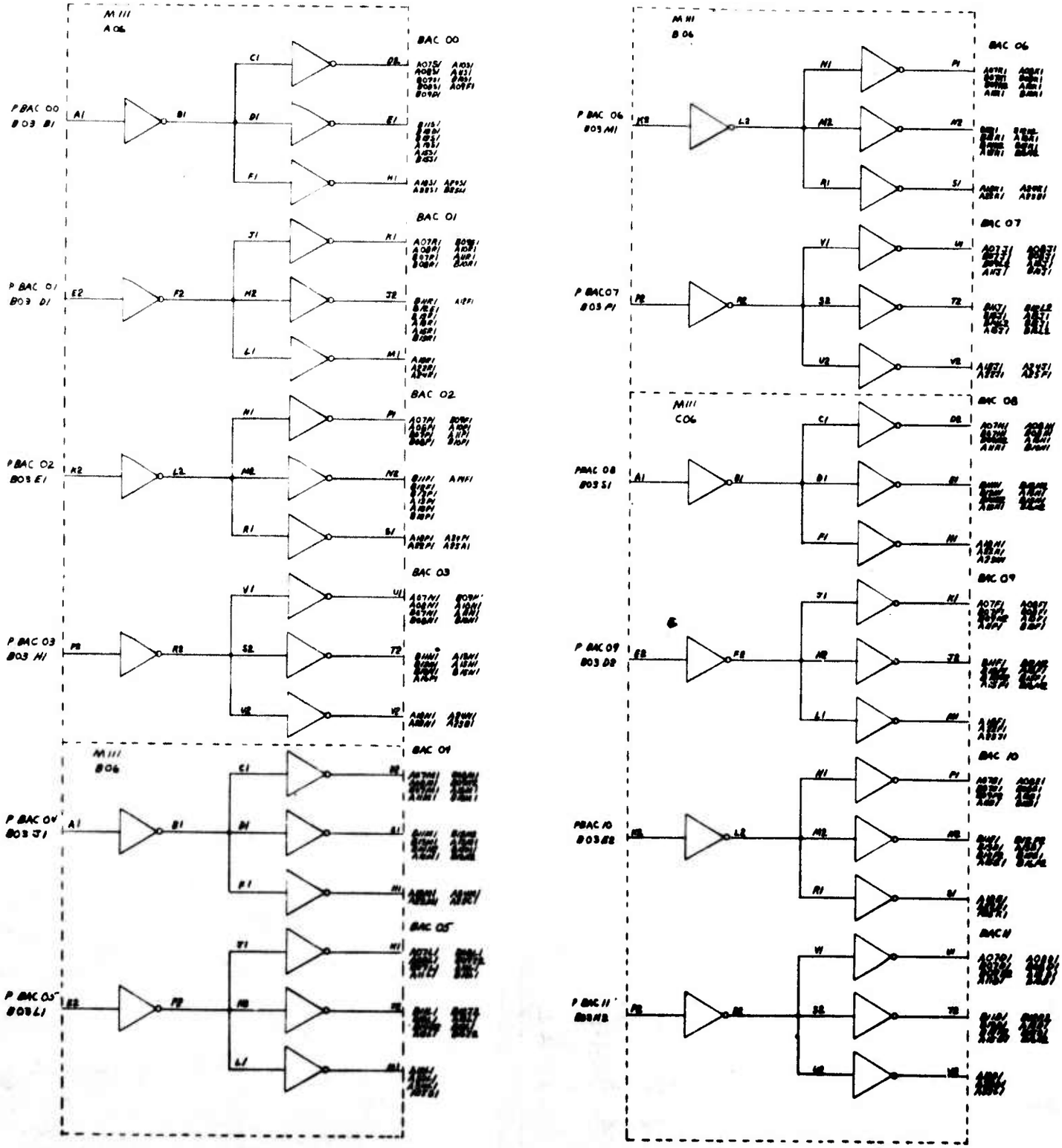


Figure B-6. Machine Level Converters and Bus Drivers


M III
A 06
BAC 00
BAC 01
BAC 02
BAC 03
M III
B 06
BAC 04
BAC 05
M III
B 04
BAC 06
BAC 07
M III
C 06
BAC 08
BAC 09
BAC 10
BAC 11

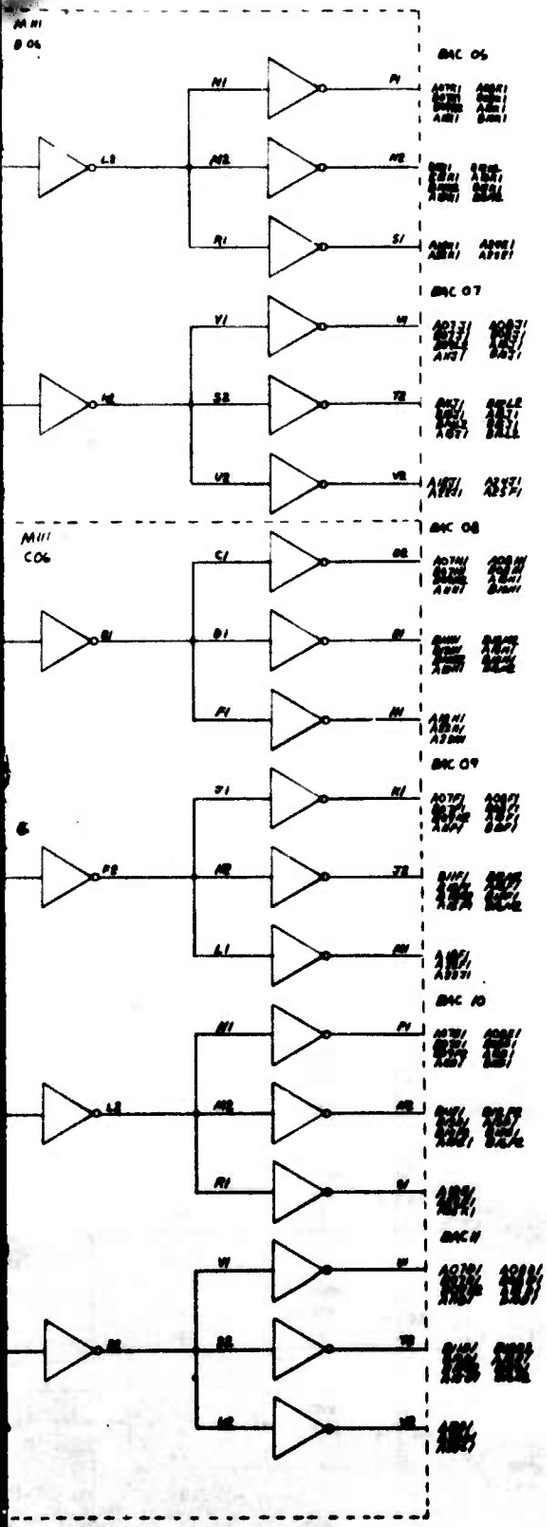
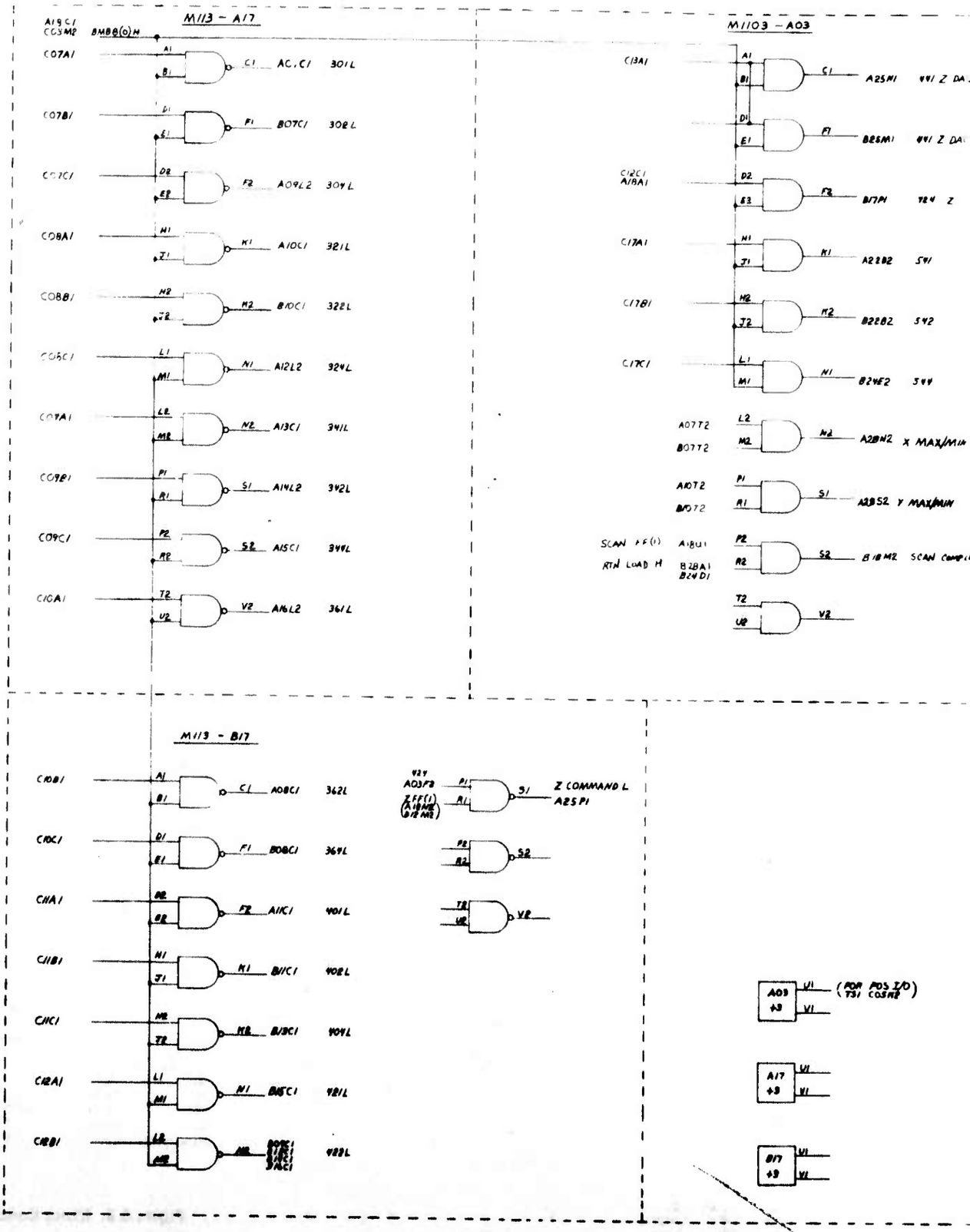


Figure B-7. BAC Driver Logic


M113 - A17
M1103 - A03
M113 - B17
BMB8(0)H
AC,C1
B07C1
A09L2
A10C1
B10C1
A12L2
A13C1
A14L2
A15C1
A16L2
A25M1
B25M1
B17P1
A22B2
B22B2
B24E2
A28N2
X MAX/MIN
A28S2
Y MAX/MIN
B18M2
SCAN COMPL
Z COMMAND L
A25P1
A03
+9
A17
+9
B17
+9
(FOR PDS I/O
TSI COSMIC)

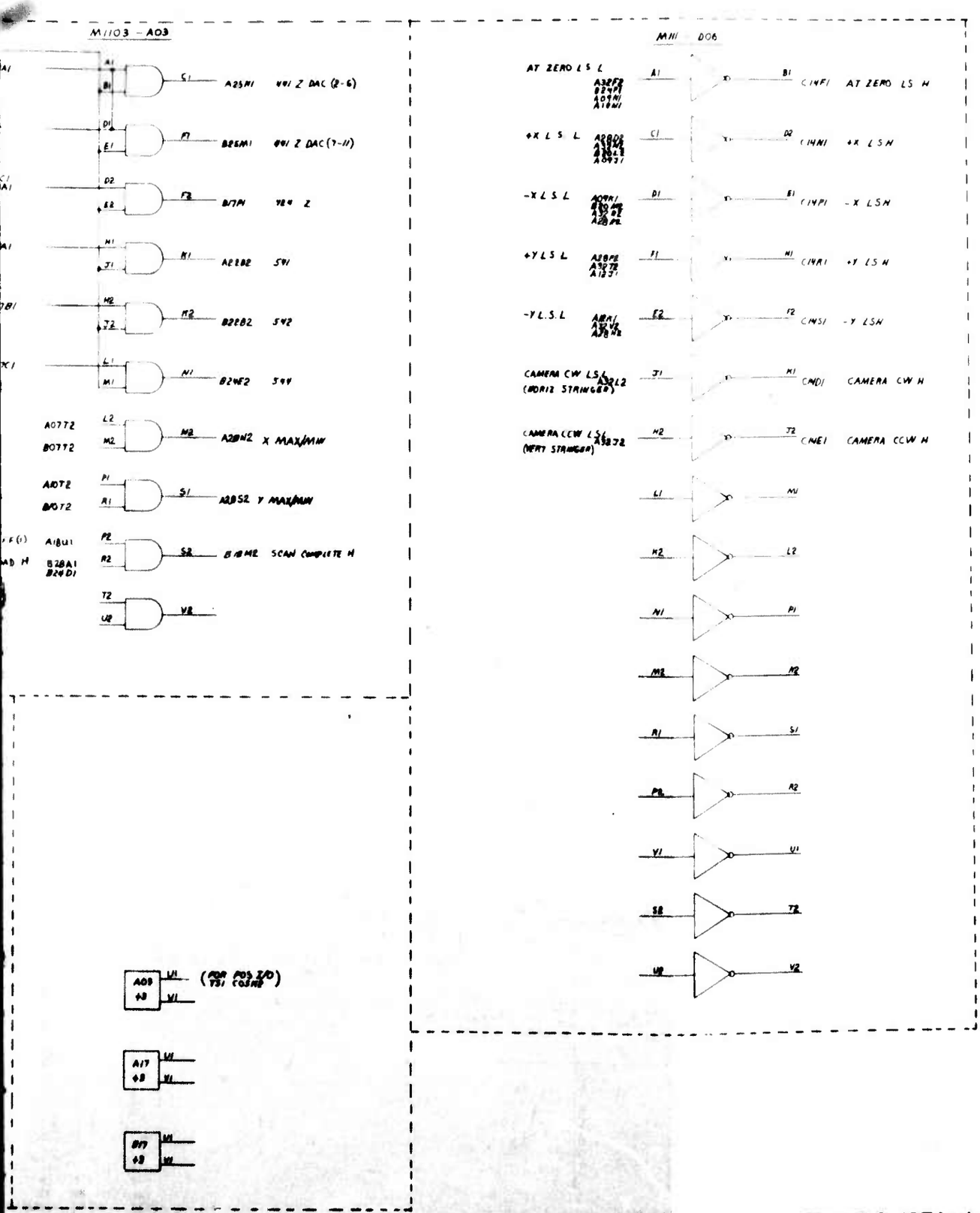
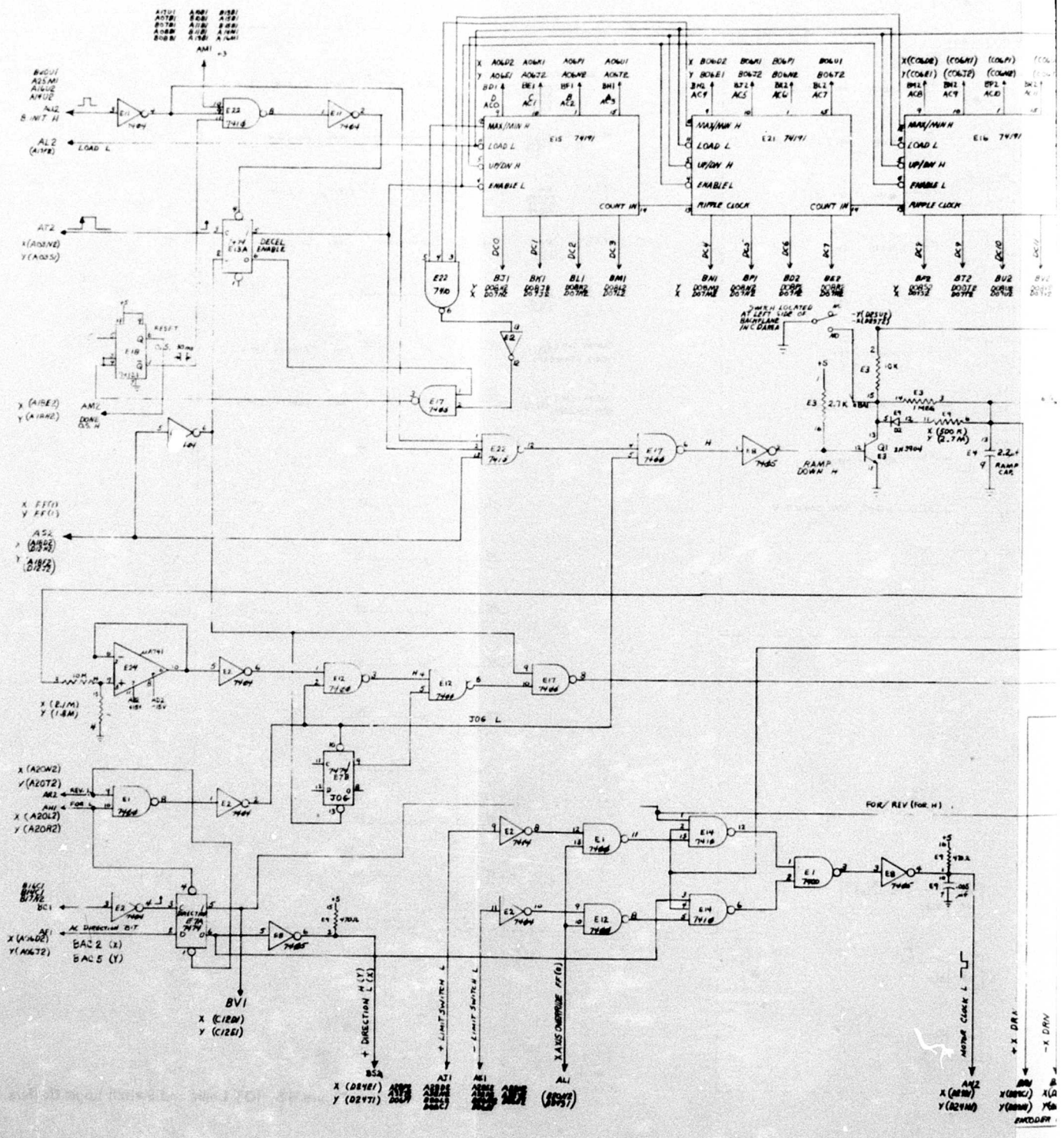


Figure B-8. IOT Logic and Switch Logic Buffers


AM1
AL2
B INIT H
LOAD L
AT2
DECEL ENABLE
RESET
AM1
DONE H
MAX/MIN H
LOAD L
UP/DN H
ENABLE L
RIPPLE CLOCK
COUNT IN
DC0
DC1
DC2
DC3
DC4
DC5
DC6
DC7
DC8
DC9
DC10
DC11
SWITCH LOCATED AT LEFT SIDE OF BACKPLANE IN CDR4A
-Y (DESVE) -ALARM (F)
+5
10K
2.7K
1MEG
X (200 M)
Y (2.7M)
1N3904
2.2µ
RAMP CAP.
RAMP DOWN H
AS2
JOG L
FOR/REV (FOR. H)
DIRECTION FF(1)
AC DIRECTION BIT
BAC 2 (X)
BAC 5 (Y)
BVI
X (C12BI)
Y (C12EI)
+ DIRECTION H (Y) (X)
+ LIMIT SWITCH L
- LIMIT SWITCH L
X AXIS OVERRIDE FF(0)
MOTOR CLOCK L
+X DRIVE
-X DRIVE
BSA
AJ1
AK1
AL1
AM2
X (D8481)
Y (D2471)
X (B2481)
Y (B2491)

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REF.	DESCRIPTION
E1, E12, E17, E23	SN 7400
E2, E11, E25	SN 7404
E8	SN 7405
E14, E22	SN 7410
E25	SN 7414
E7, E13	SN 7474
E6, E18, E19	SN 74121
E15, E16, E21	SN 74191
E24	UA 741
E20	SN 15846
Q1	2N3904
Q2	TIS 75
Q3	2N 492
D1, D2	IN 914

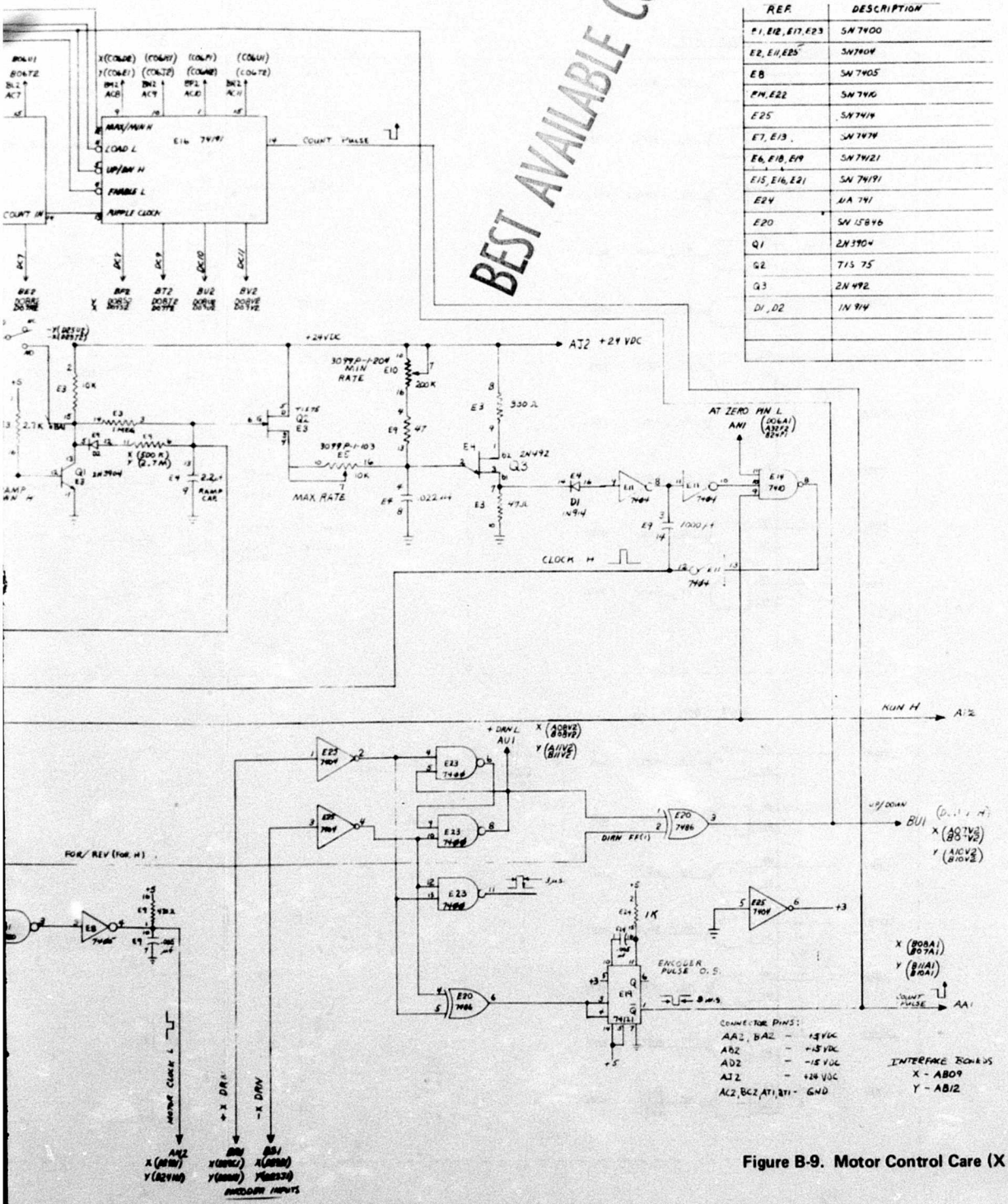
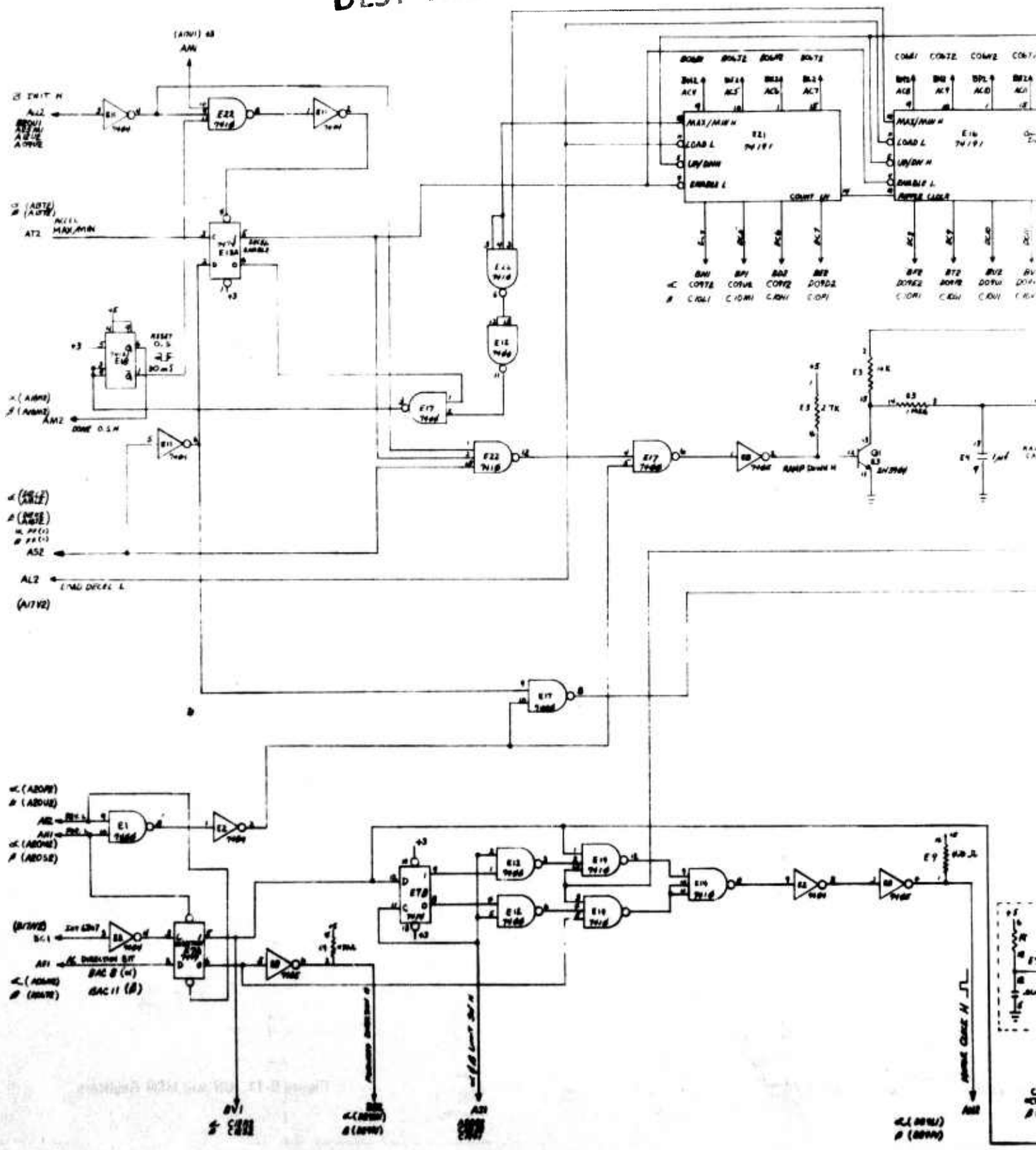


Figure B-9. Motor Control Care (X and Y Axes)

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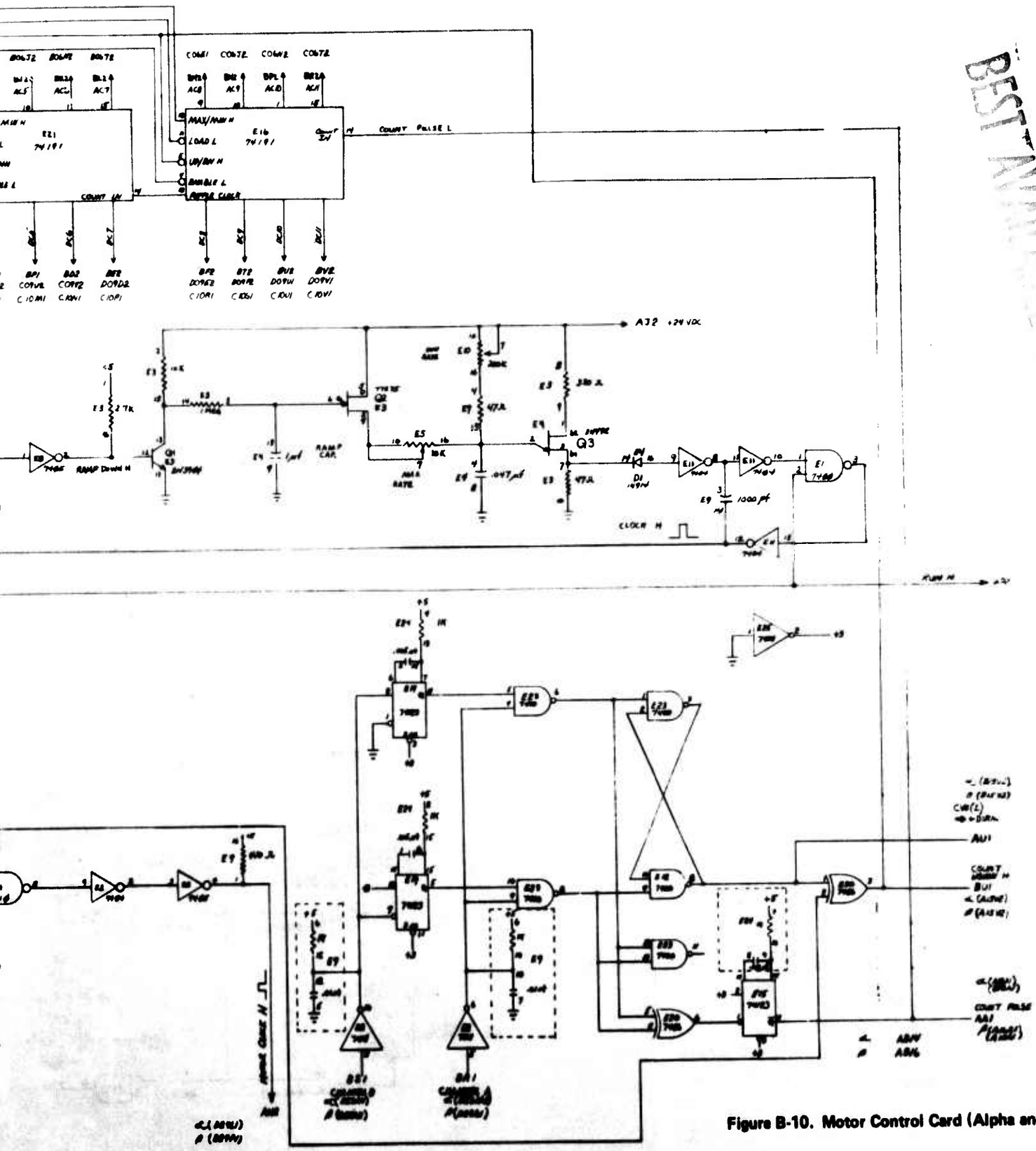
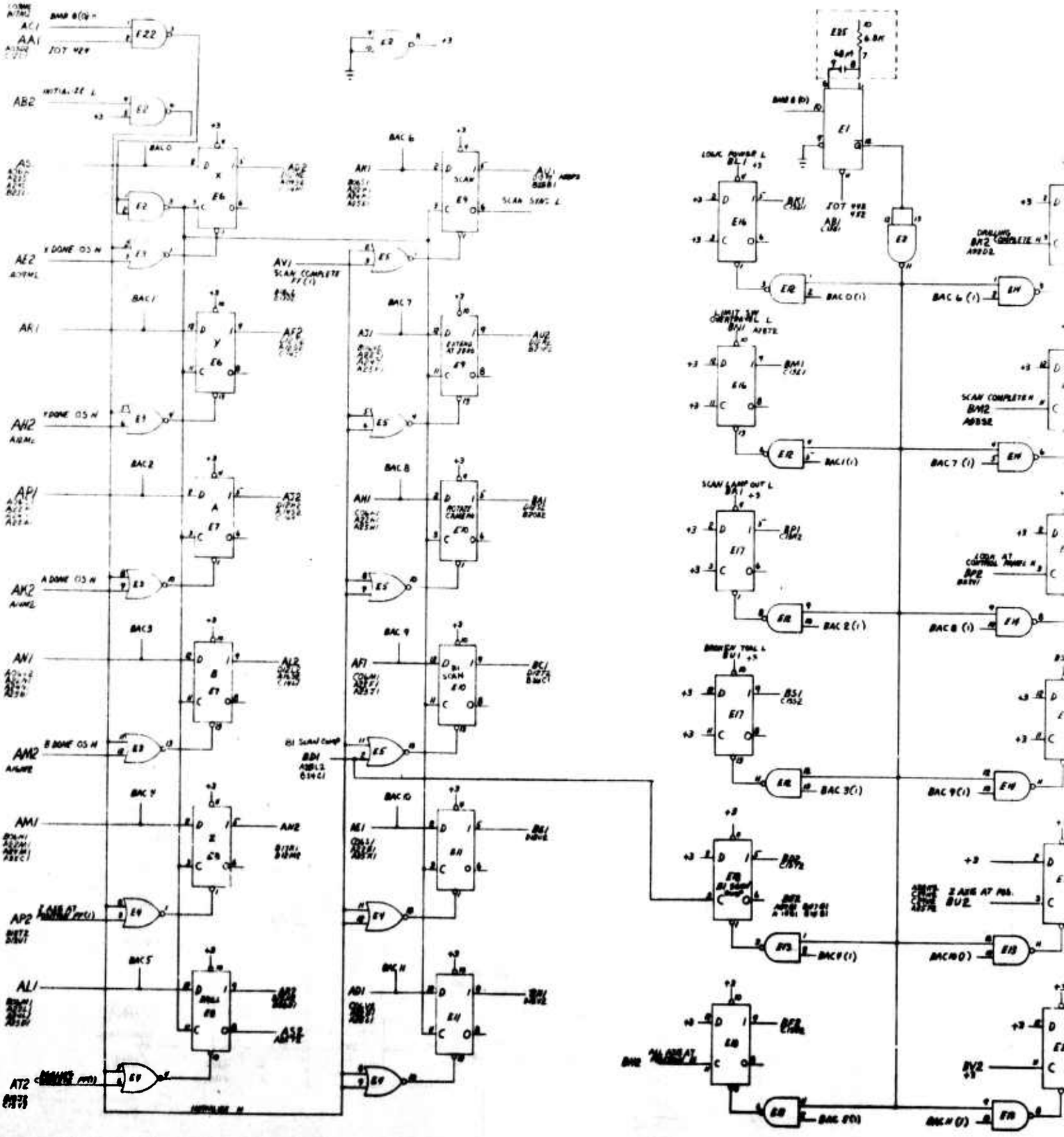
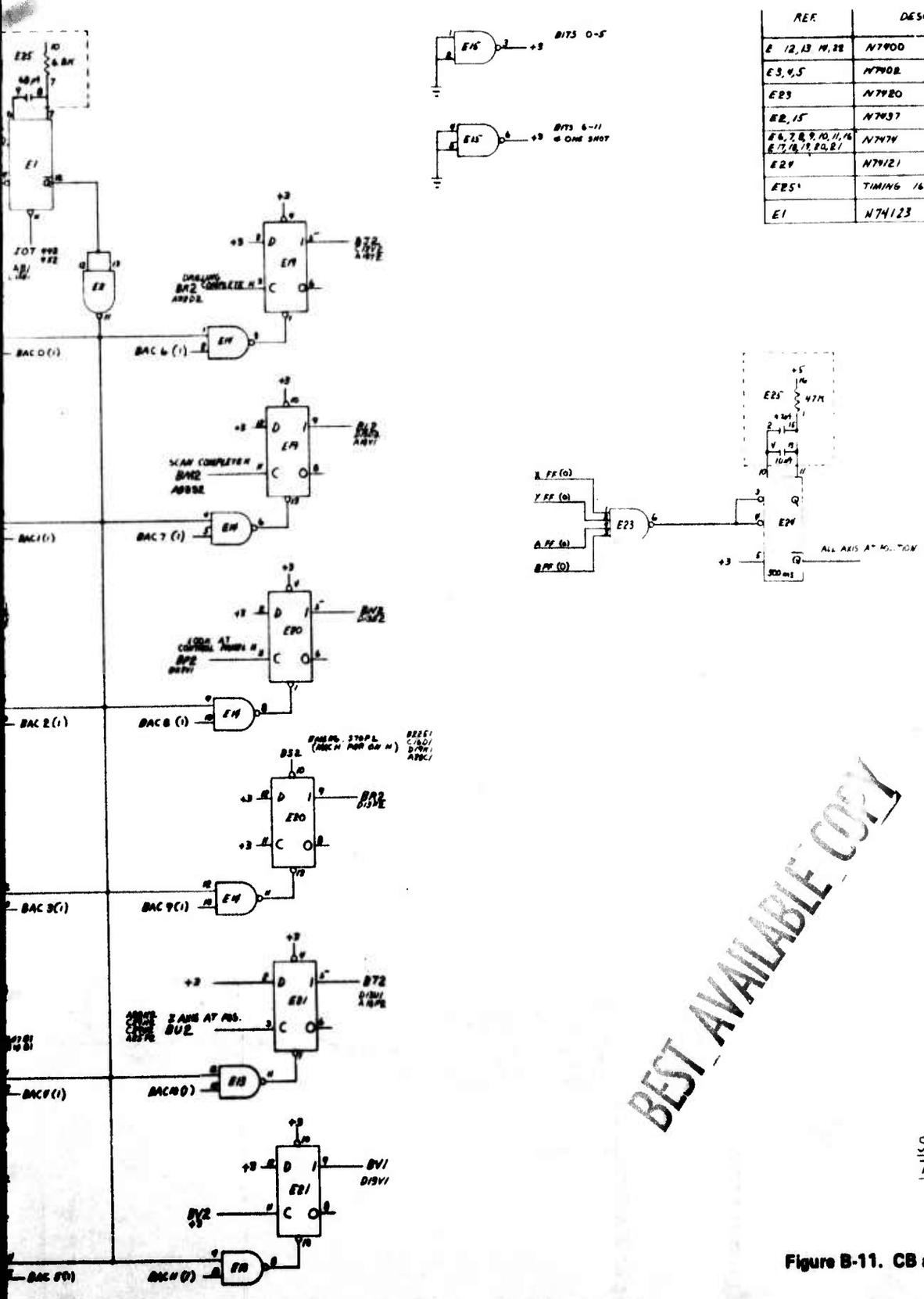


Figure B-10. Motor Control Card (Alpha and Beta Axes)

2





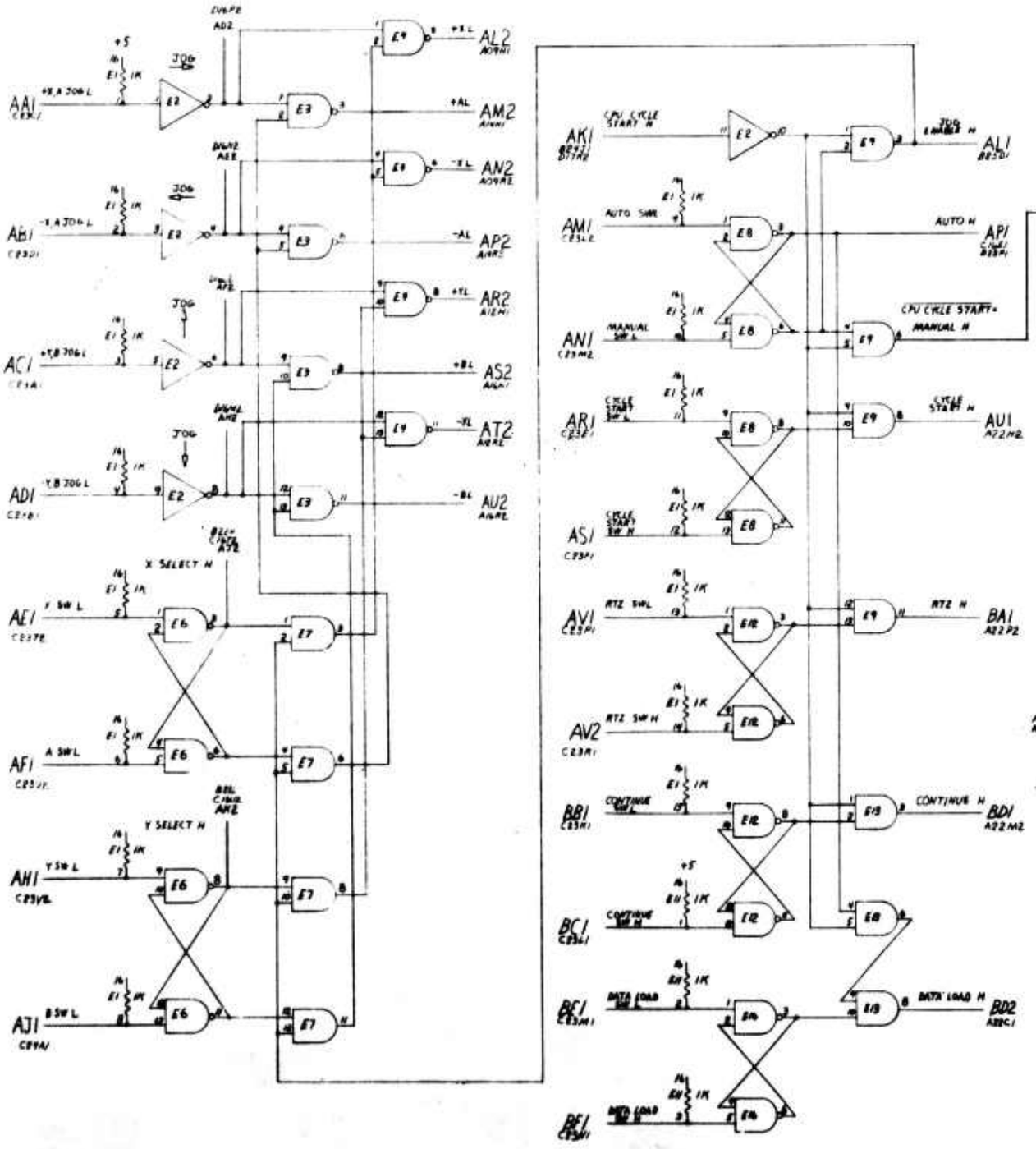
REF.	DESCRIPTION
E 12, 13 14, 22	N7400
E 3, 4, 5	N7402
E 23	N7420
E 2, 15	N7437
E 6, 7, 8, 9, 10, 11, 16 E 17, 18, 19, 20, 21	N7474
E 24	N74121
E 25	TIMING 16 PIN
E 1	N74123

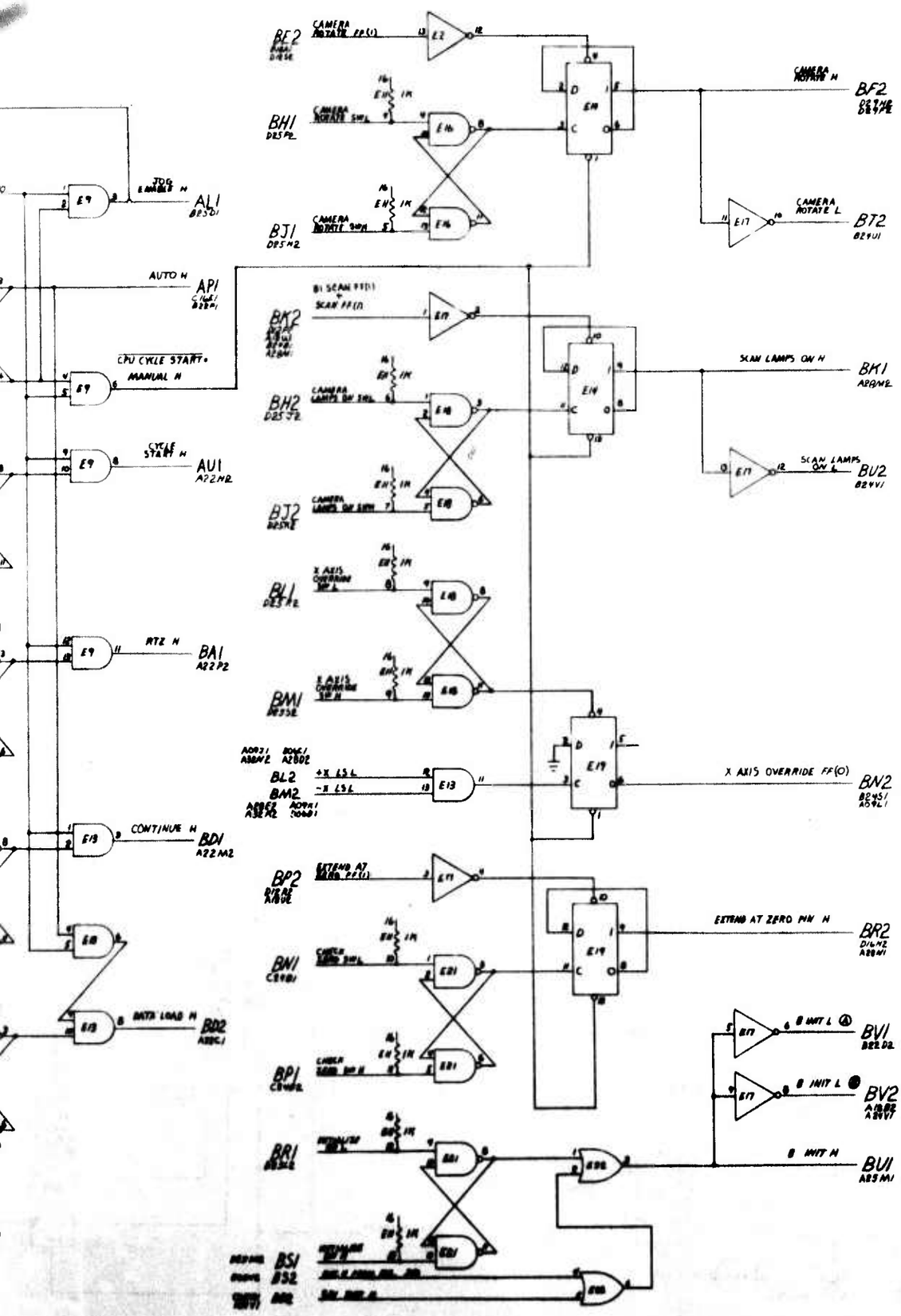
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SLOT AB18
TYPE WP13

Figure B-11. CB and HSR Registers

2


AAI
ABI
ACI
ADI
AEI
AFI
AHI
AJI
AL2
AM2
AN2
AP2
AR2
AS2
AT2
AU2
AKI
AMI
ANI
ARI
ASI
AVI
AV2
BBI
BCI
BFI
AL1
API
AU1
BAI
BDI
BD2
+5
JOG
X SELECT H
Y SELECT H
AUTO H
MANUAL H
CONTINUE H
RTZ H
DATA LOAD H

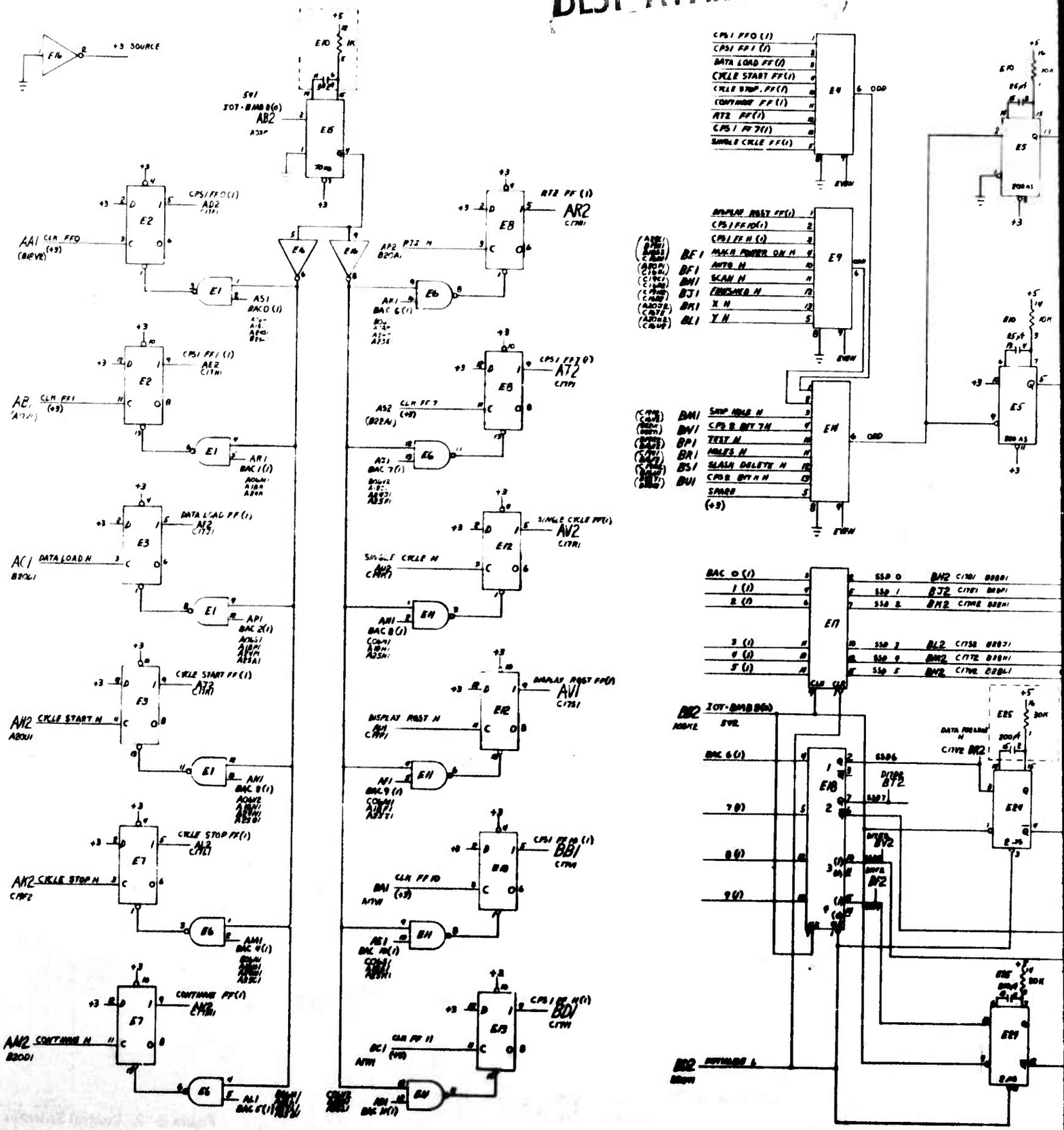


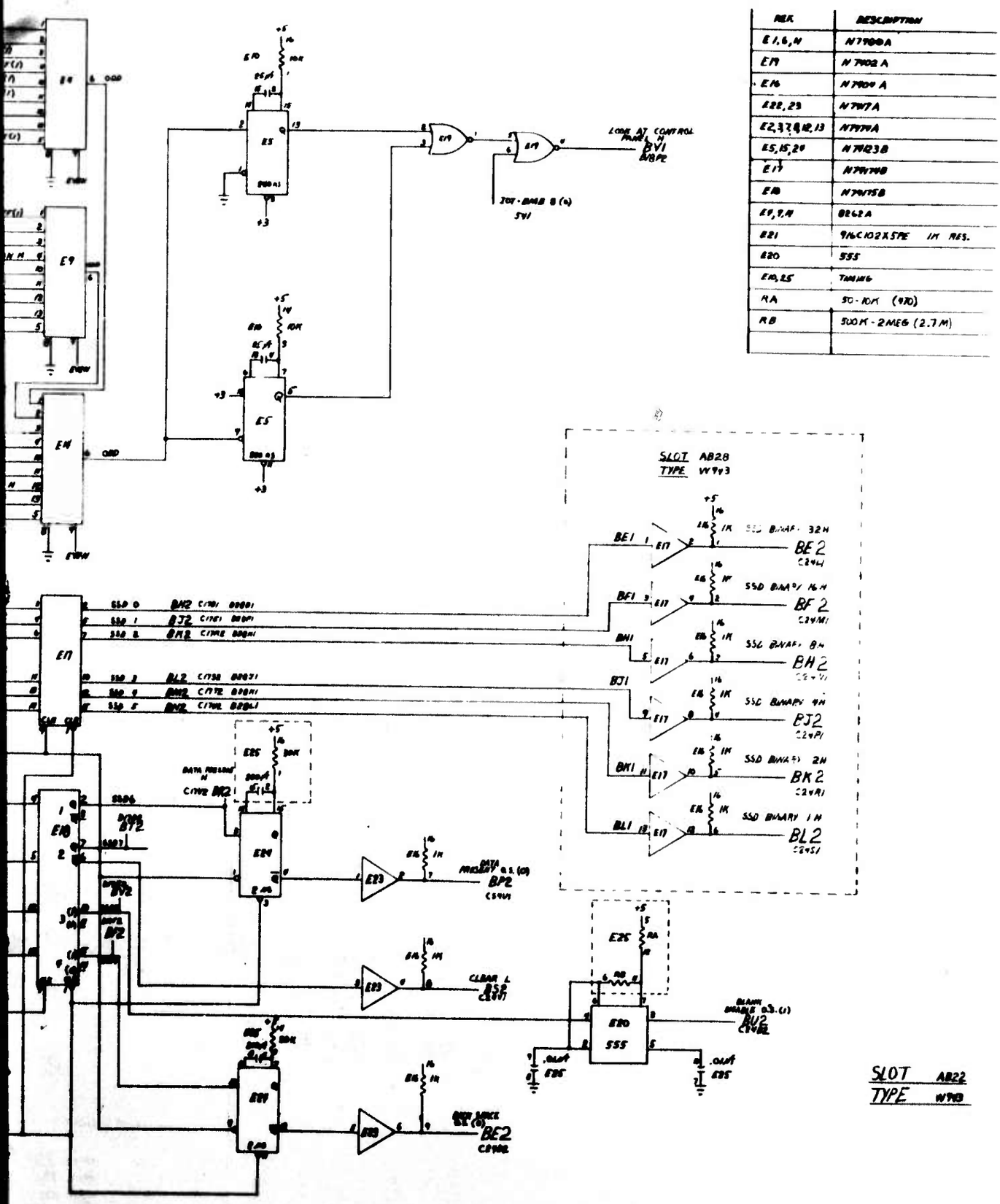
REF	DESCRIPTION
E3,9,6,8,12,16,18,21	N7400A
E2, 17	N7404A
E7, 9, 13	N7408A
E22	N7432A
E14, 19	N7474A
E1, 11	9N6C/102A5PE

SLOT AB20
TYPE W943

Figure B-12. Control Switches

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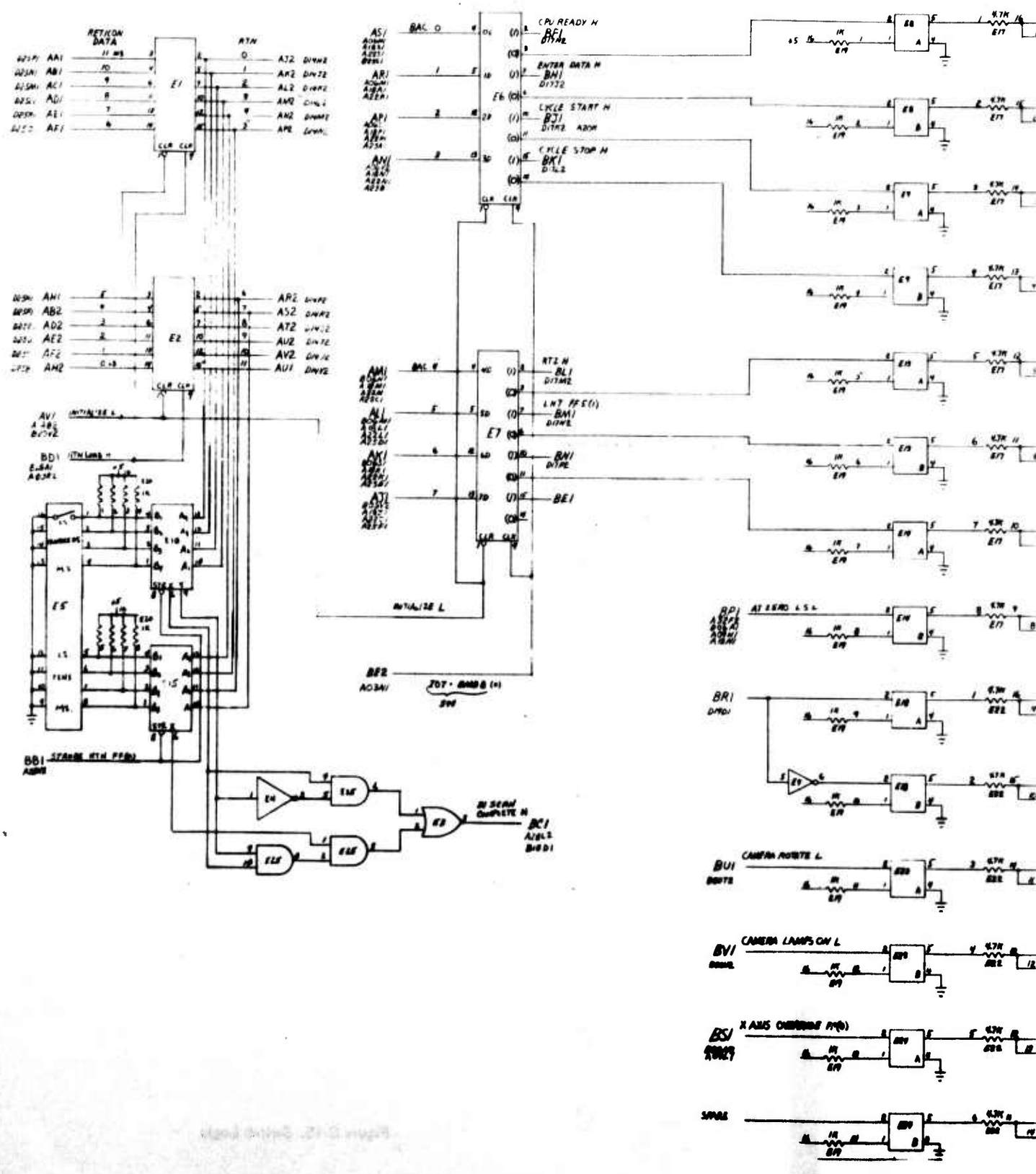


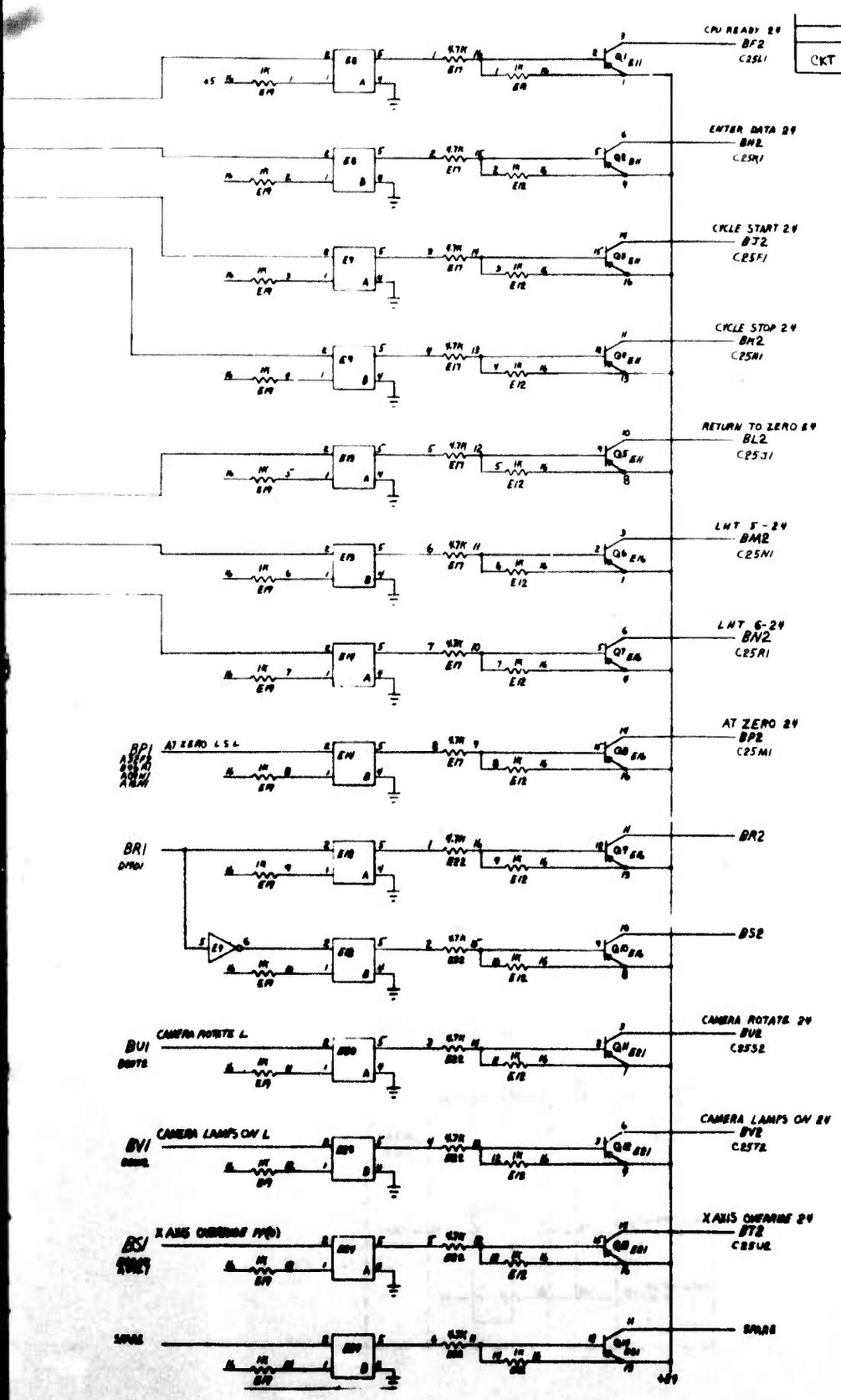


REF.	DESCRIPTION
E1,6,N	N7400A
E19	N 7402 A
E16	N 7404 A
E22,23	N 7417 A
E2,3,7,8,12,13	N7420A
E5,15,24	N 7423B
E17	N74174B
E18	N74175B
E9,11,N	8262A
E21	9116C102X5PE 1M RES.
E20	555
E10,25	TIMING
RA	50-10M (470)
RB	500K-2MEG (2.7M)

Figure B-13. Control Panel and SSD

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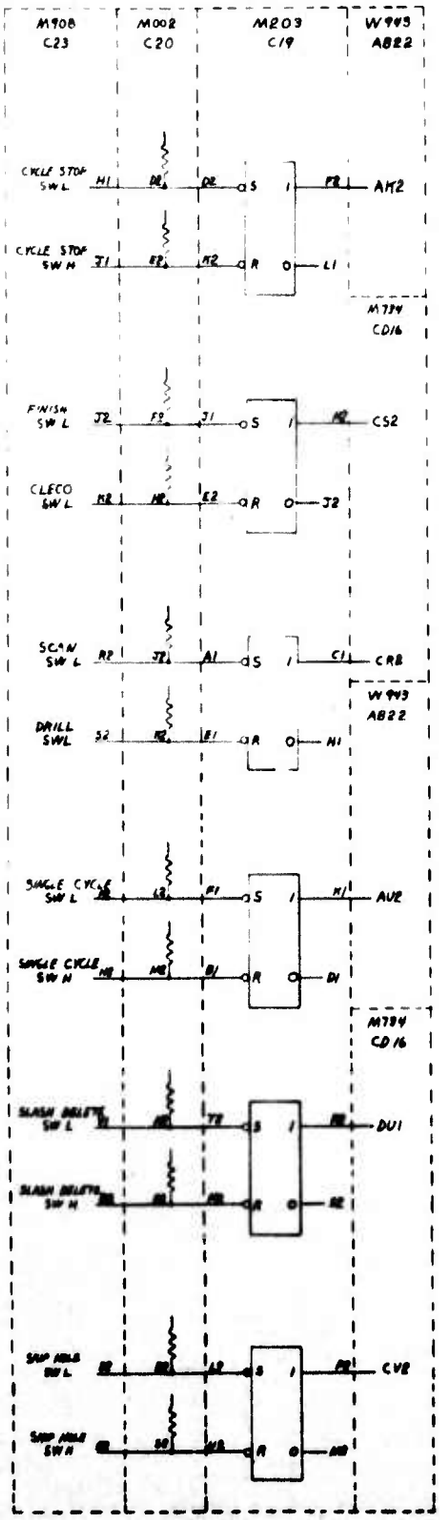


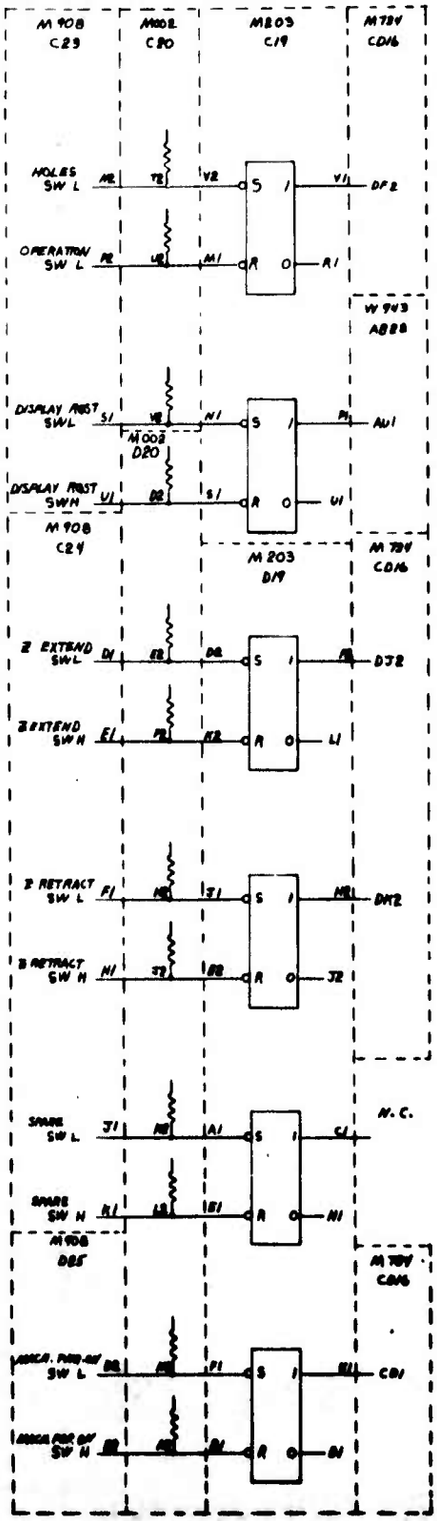


REVISIONS			
DESCRIPTION		DATE	APPD
ADD CKT FOR BI SCAN		11/4/76	

REF.	DESCRIPTION
E9	N7404A
E8	N7010A
E1,2	N7411A B
E4,7	N7412A B
E3,6,13,14 E20,23,24	MC831
E12,19	1K
E15,22	9.7K
E17,16,21	TRANS
E18, 15	N8269A
E5	SLIDE SW'S
E25	N7408A

Figure B-14. Reticon and Lamp Drive


M908 C23
M002 C20
M203 C19
W993 AB22
CYCLE STOP SW L
CYCLE STOP SW H
M734 CD16
FINISH SW L
CLECO SW L
SCAN SW L
DRILL SW L
W993 AB22
SINGLE CYCLE SW L
SINGLE CYCLE SW H
M734 CD16
SLASH DELETE SW L
SLASH DELETE SW H
SKIP HOLE SW L
SKIP HOLE SW H


M908 C23
M002 C20
M203 C19
M734 CD16
HOLES SW L
OPERATION SW L
W993 AB22
DISPLAY FAST SW L
M002 D20
DISPLAY FAST SW H
M908 C24
M203 D19
M734 CD16
Z EXTEND SW L
Z EXTEND SW H
Z RETRACT SW L
Z RETRACT SW H
M734 CD16
SPARE SW L
SPARE SW H
N.C.
M908 D25
M734 CD16

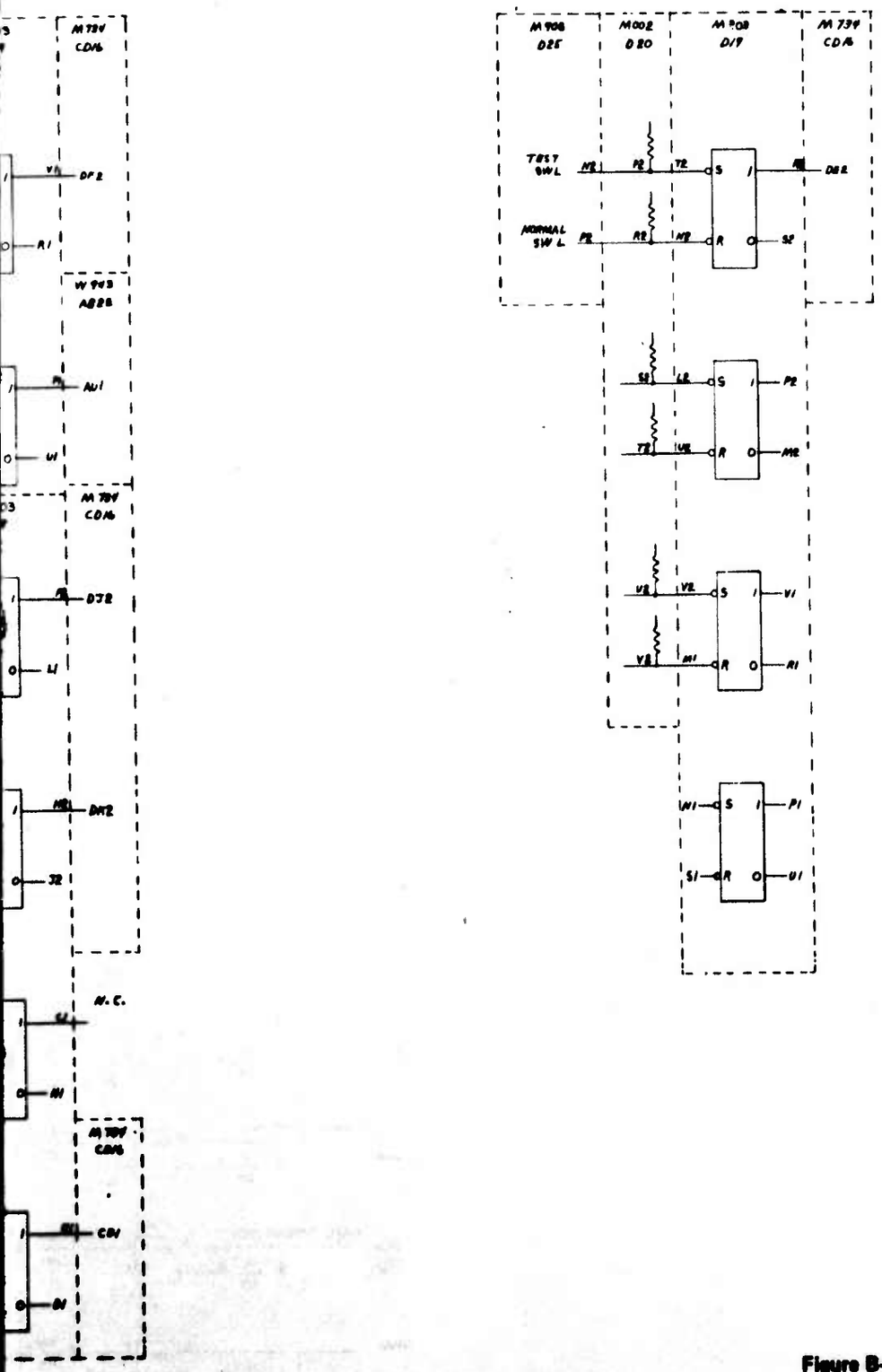


Figure B-15. Switch Logic

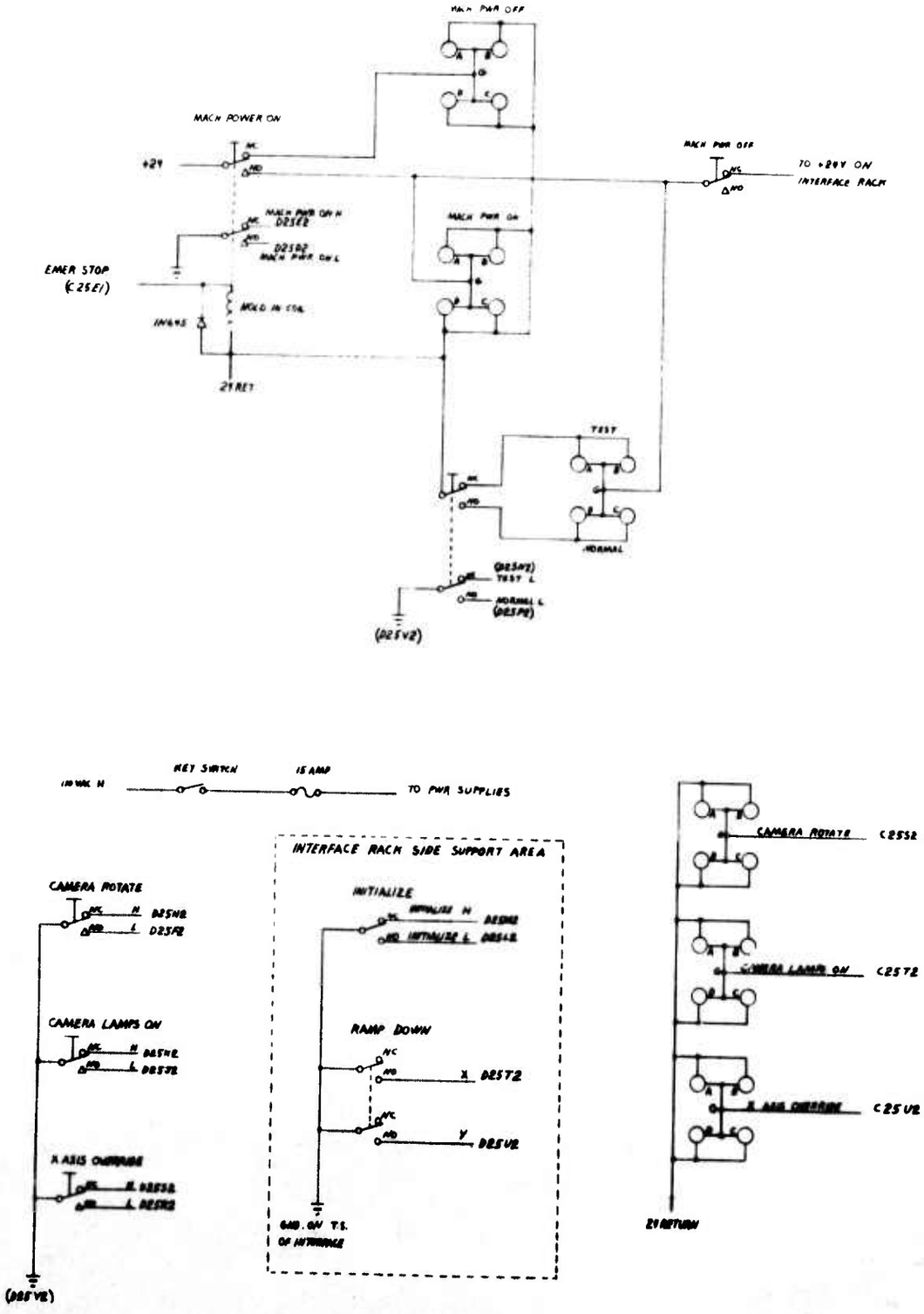
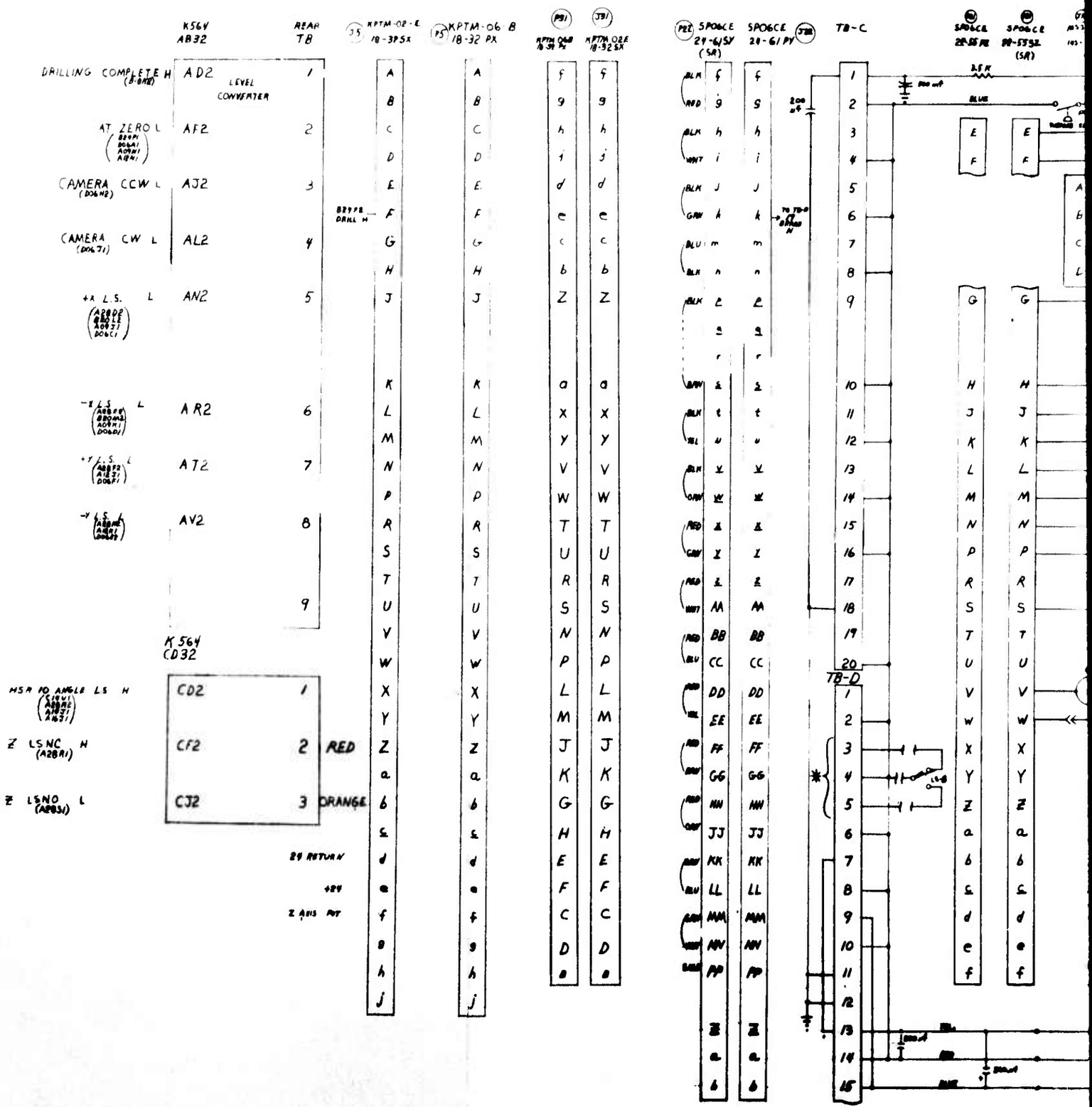


Figure B-16. Interface Cabinet Switch Panel


K564
AB32
REAR
TB
J5 KPTM-02-E
18-32SX
P5 KPTM-06-B
18-32 PX
P51
J51
P52
J52
TB-C
TB-D
DRILLING COMPLETE H
LEVEL CONVERTER
AT ZERO L
CAMERA CCW L
CAMERA CW L
+A L.S. L
-X L.S. L
+Y L.S. L
-Y L.S. L
AD2
AF2
AJ2
AL2
AN2
AR2
AT2
AV2
K564
CD32
CD2
CF2
CJ2
MSR TO ANGLE LS H
Z LS NC H
Z LS NO L
RED
ORANGE
29 RETURN
+29
Z AXIS POT
SPOGCE
29-61SV
(SR)
SPOGCE
29-61PV
SPOGCE
29-53SL
(SR)
BLUE
BLK
RED
WHT
GRN
BRN
YEL
GRY
VIO

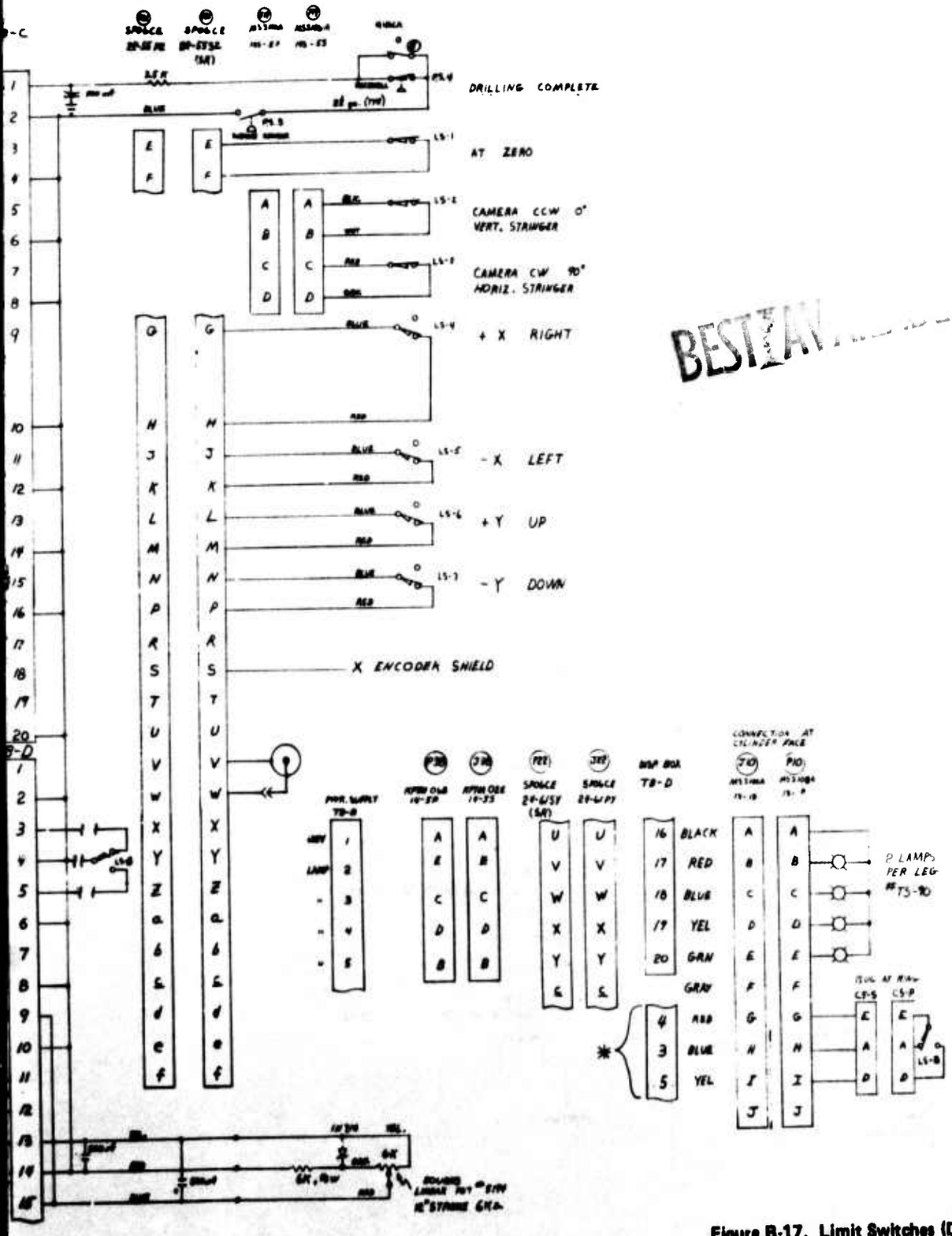
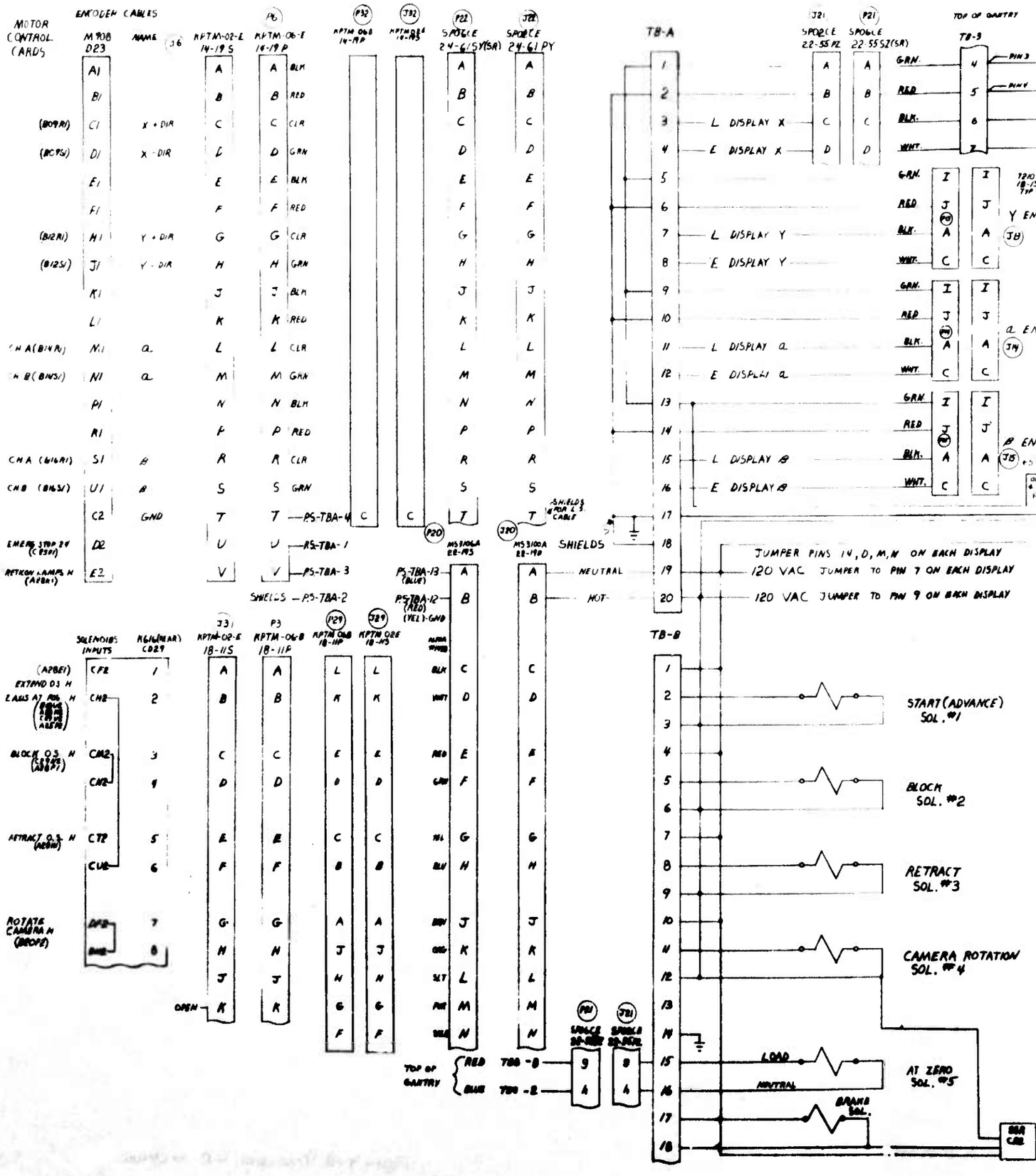
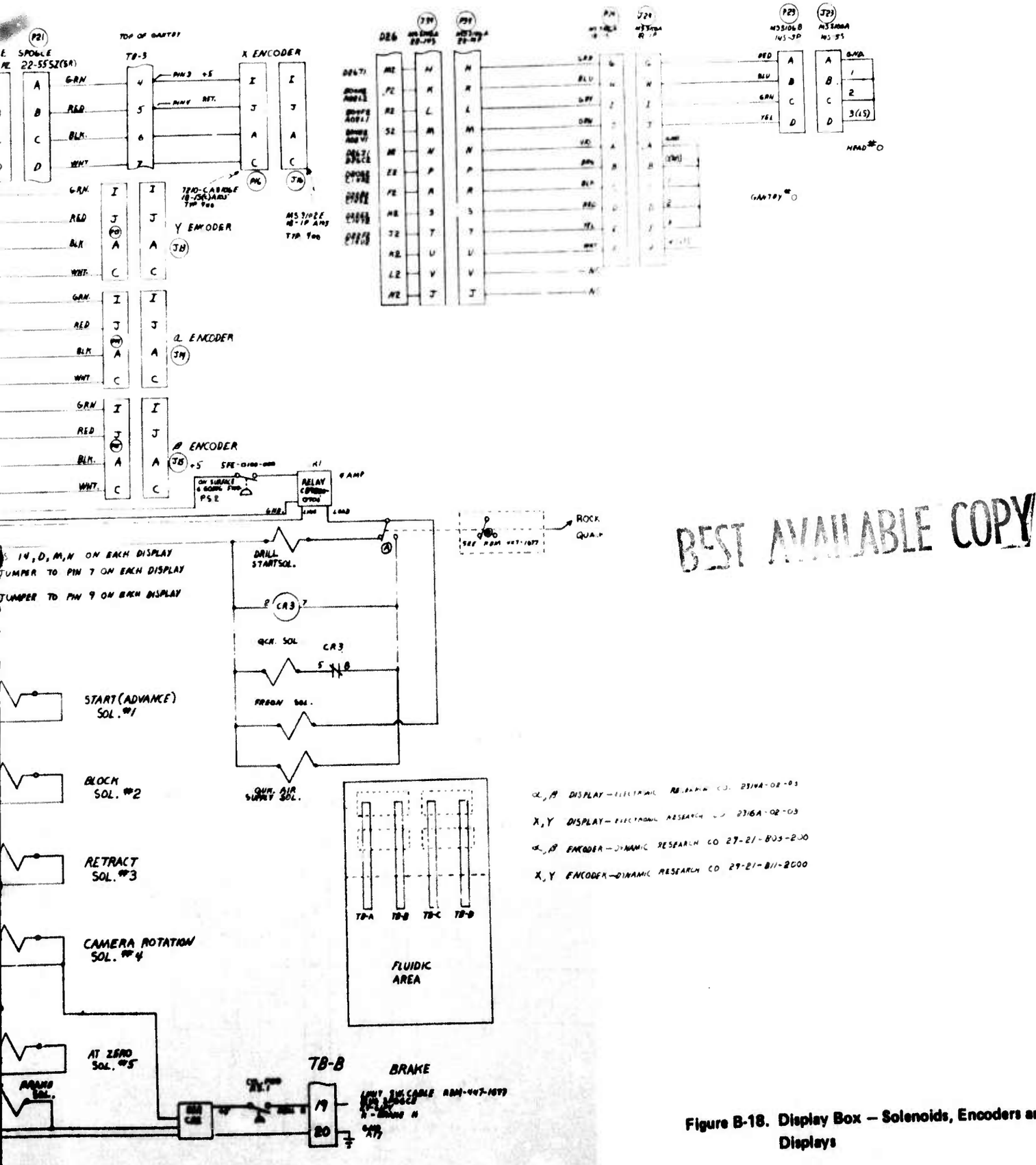


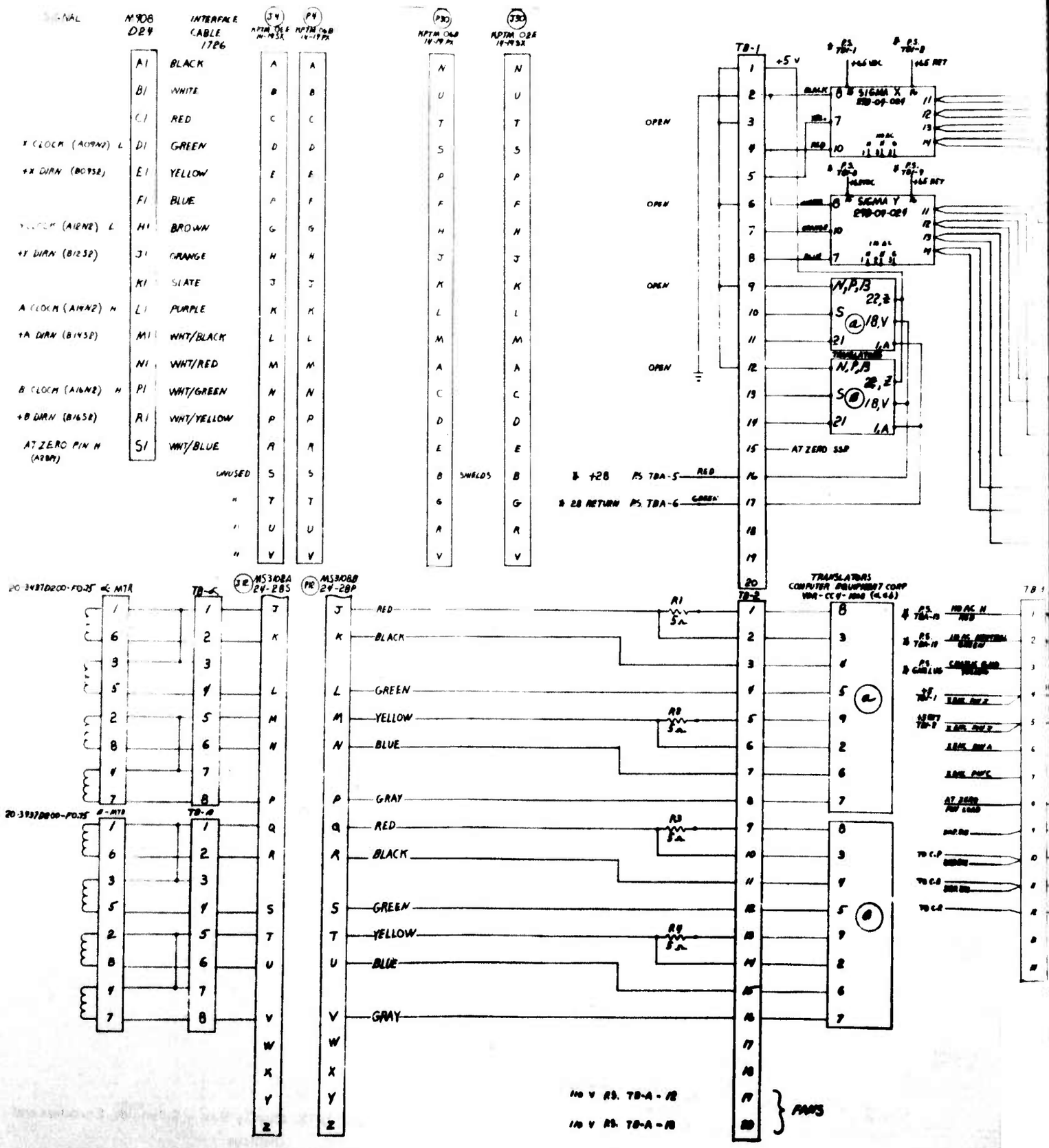
Figure B-17. Limit Switches (Display Box)

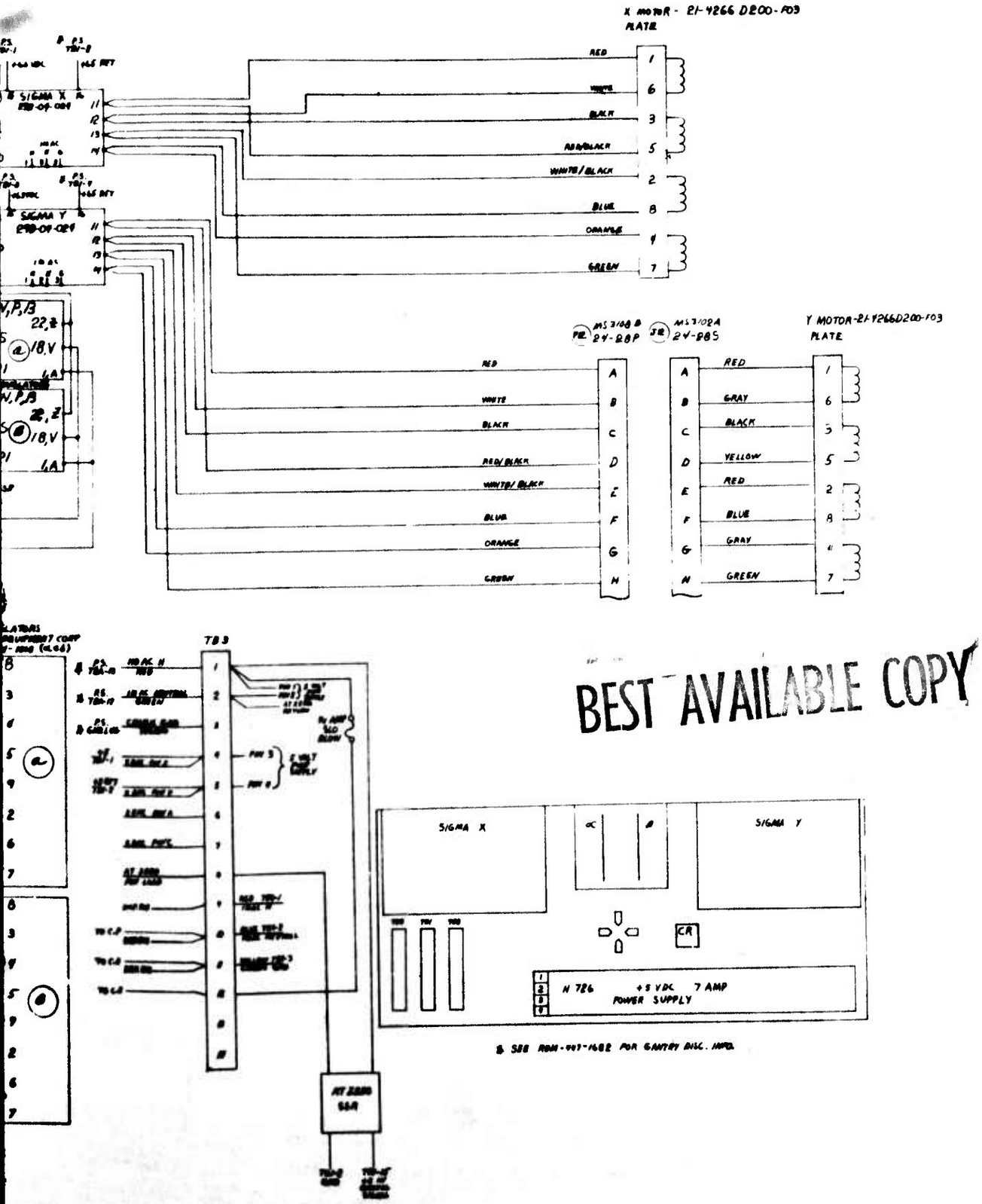

MOTOR CONTROL CARDS
ENCODER CABLES
M908 D23
NAME
J6
RPTM-02-E 14-19 S
P6
RPTM-06-E 16-19 P
P32
RPTM 06B 16-19P
J32
RPTM 06E 16-19S
P22
SPRAGUE 24-61SY(SR)
J22
SPRAGUE 24-61PY
TB-A
J21
SPRAGUE 22-55 PZ
P21
SPRAGUE 22-55SZ(SR)
TOP OF GANTRY
TB-9
L DISPLAY X
E DISPLAY X
L DISPLAY Y
E DISPLAY Y
L DISPLAY a
E DISPLAY a
L DISPLAY B
E DISPLAY B
SHIELDS
NEUTRAL
HOT
JUMPER PINS 14, D, M, N ON EACH DISPLAY
120 VAC JUMPER TO PIN 7 ON EACH DISPLAY
120 VAC JUMPER TO PIN 9 ON EACH DISPLAY
TB-8
SOLENOIDS INPUTS
REG(REAR) CD29
J31
RPTM-02-E 18-11S
P3
RPTM-06-B 18-11P
P29
RPTM 06B 18-11P
J29
RPTM 02E 18-11S
P20
MS3106A 22-19S
J20
MS3100A 22-19P
START (ADVANCE) SOL. #1
BLOCK SOL. #2
RETRACT SOL. #3
CAMERA ROTATION SOL. #4
AT ZERO SOL. #5
LOAD
NEUTRAL
BRAKE SOL.
P31
SPRAGUE 22-55PZ
J31
SPRAGUE 22-55SZ
TOP OF GANTRY
RED
BLUE
TB8 -B
TB8 -E
OPEN



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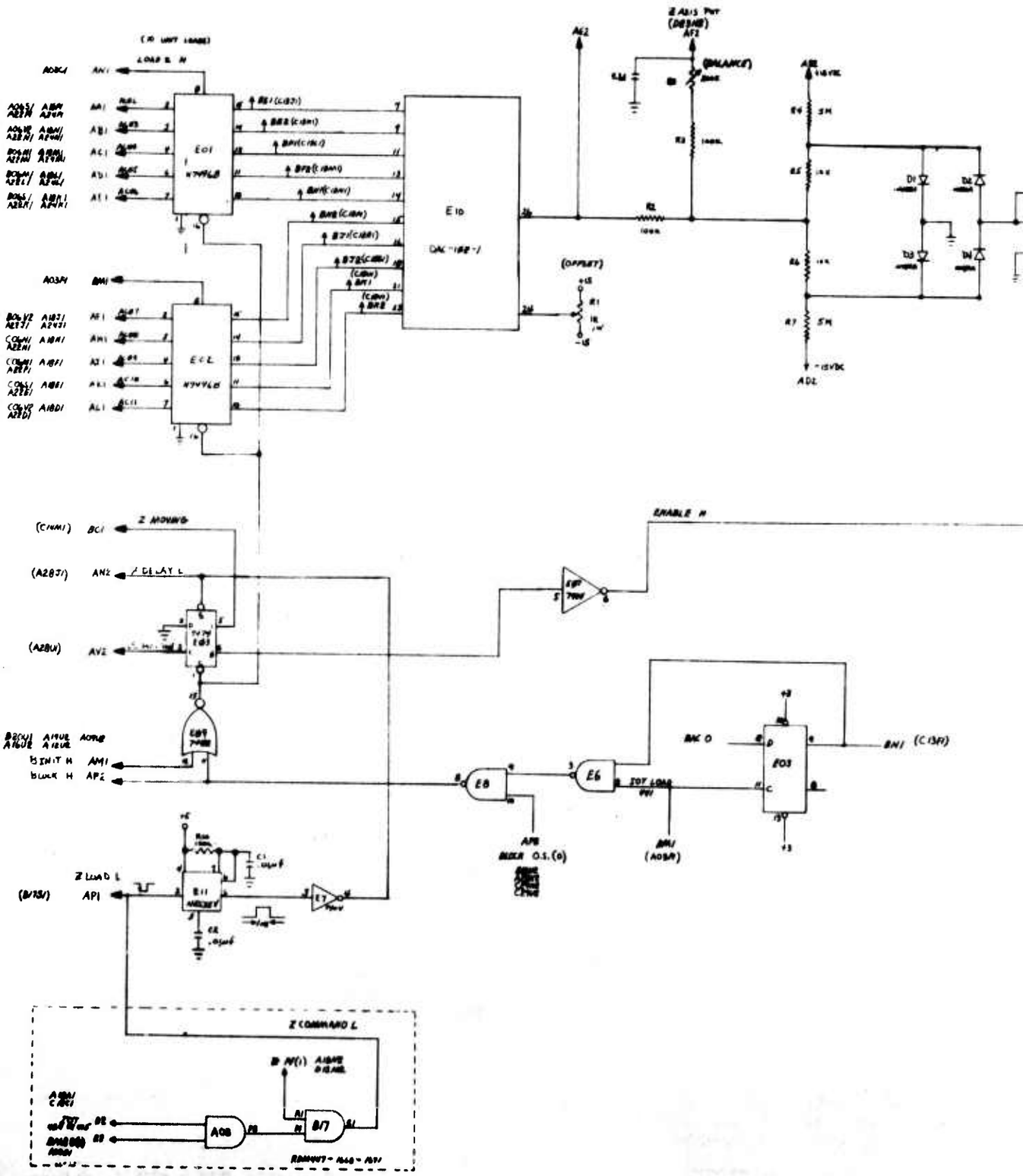
Figure B-18. Display Box — Solenoids, Encoders and Displays

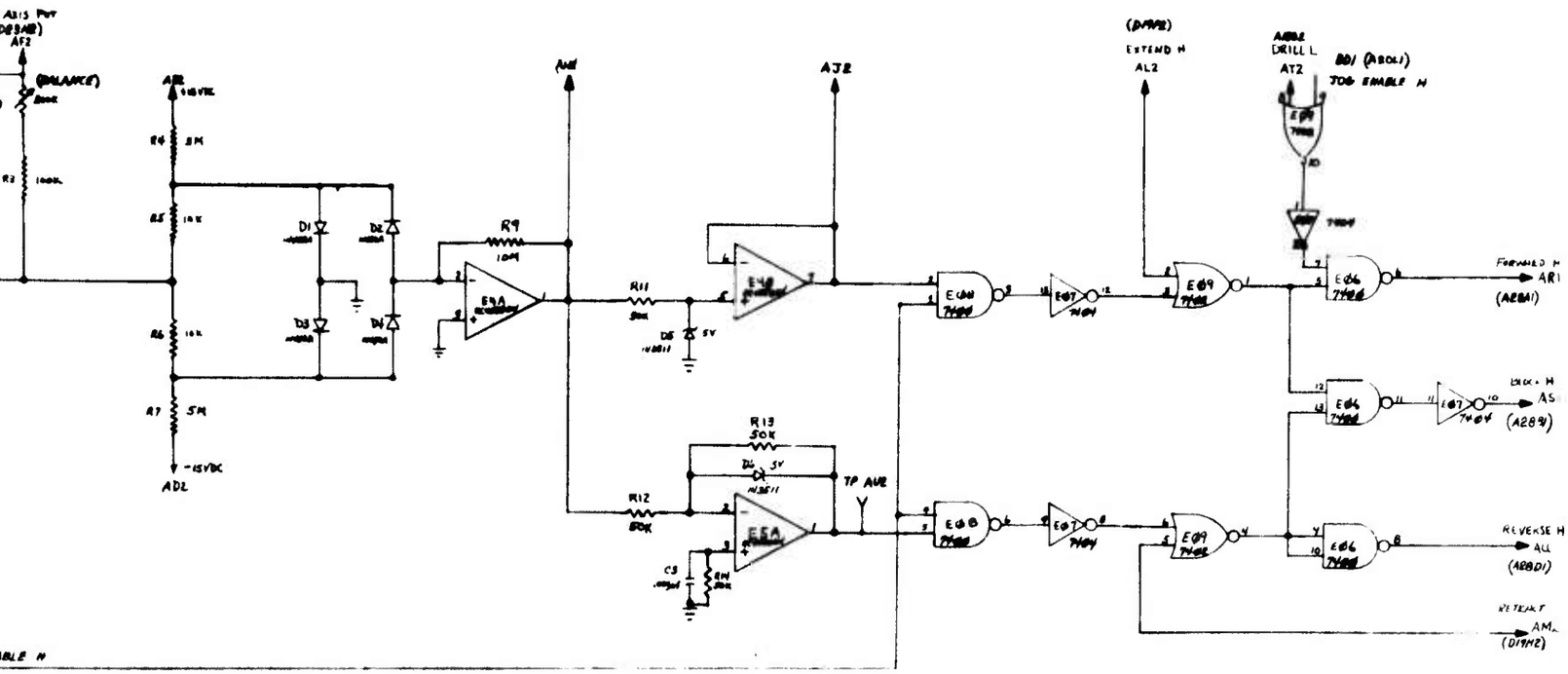

SIGNAL
M908 D24
INTERFACE CABLE 1726
J4 MPTM 0&E 14-19SX
P4 MPTM 0&B 14-19PX
P30 MPTM 0&B 14-19PX
J30 MPTM 0&E 14-19SX
X CLOCK (A0INH2) L
+X DIRN (B0152)
Y CLOCK (A1INH2) L
+Y DIRN (B1252)
A CLOCK (A1INH2) H
+A DIRN (B1452)
B CLOCK (A1INH2) H
+B DIRN (B1652)
AT ZERO PIN H (A2BP1)
BLACK
WHITE
RED
GREEN
YELLOW
BLUE
BROWN
ORANGE
SLATE
PURPLE
WHT/BLACK
WHT/RED
WHT/GREEN
WHT/YELLOW
WHT/BLUE
UNUSED
SHIELDS
TB-1
+5 V
OPEN
SIGMA X CTD-09-001
SIGMA Y CTD-09-001
AT ZERO SSP
+28 PS TBA-5 RED
28 RETURN PS TBA-6 GREEN
TB-2
TRANSLATORS COMPUTER EQUIPMENT CORP VMA-CC4-1000 (4.44)
TB-9
J8 MS3108A 24-28S
P8 MS3108B 24-28P
20-3937D200-F0.25
TB-6
TB-10
RED
BLACK
GREEN
YELLOW
BLUE
GRAY
R1
R2
R3
R4
110 V RS. TB-A-18
110 V RS. TB-A-18
FANS



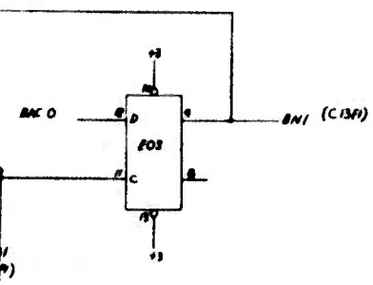
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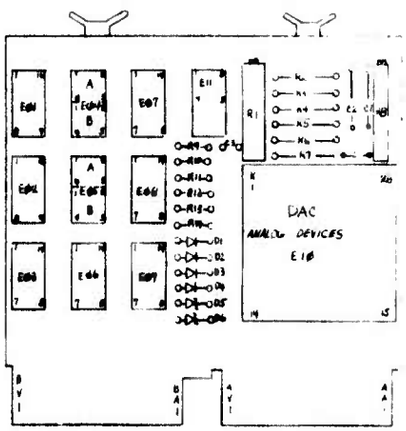
Figure B-19. Translators – Drive System


Z AXIS POT (DB9MB)
(BALANCE)
(OFFSET)
E10
DAC-1152-1
E01
ECL
E8
E6
E03
E7
E11
MONOST
Z MOVING
/ DELAY L
ENABLE H
Z LOAD L
Z COMMAND L
A08
B/7
INIT H
BLANK H
+15V
-15V



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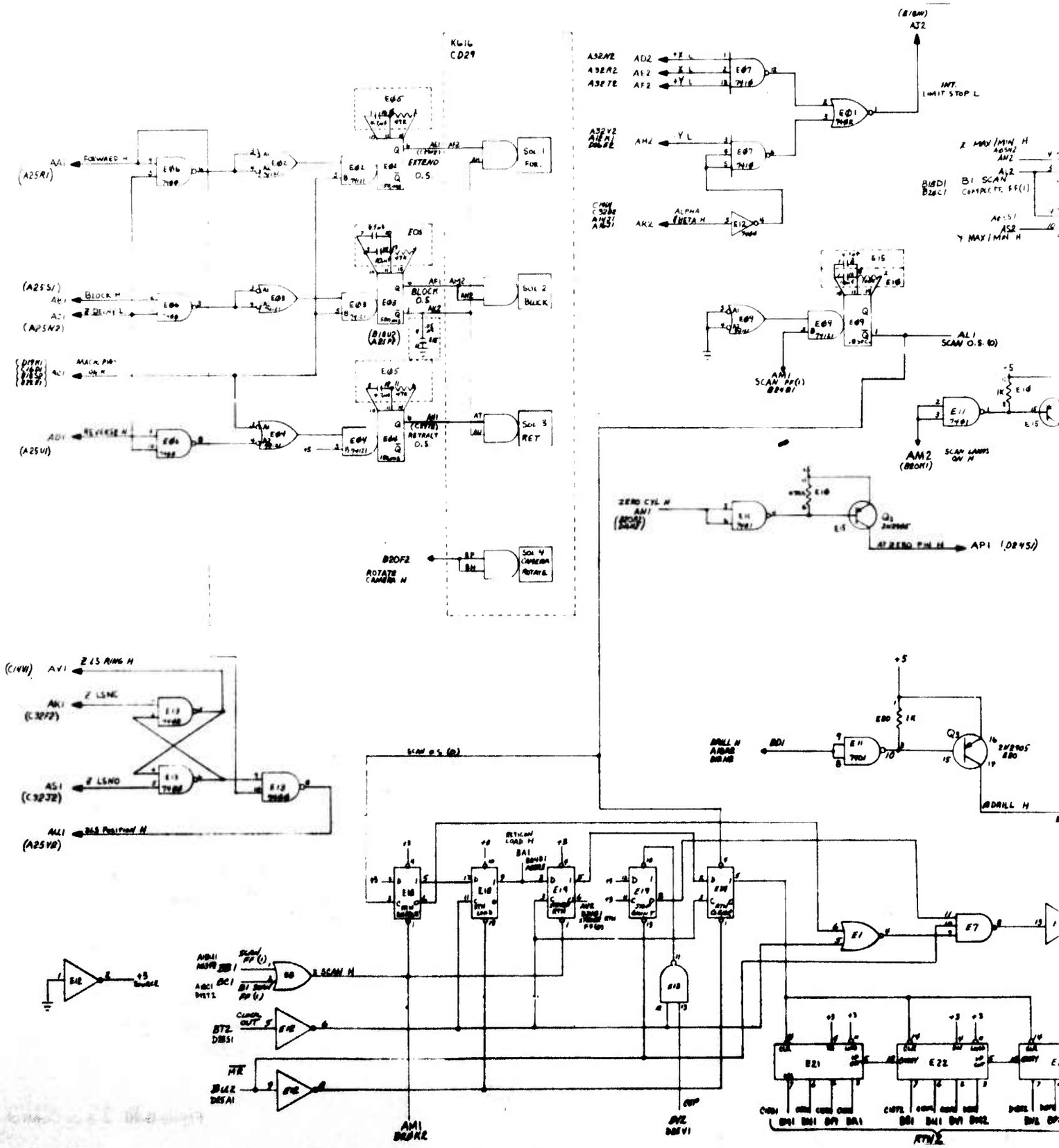
LAYOUT SIDE 1

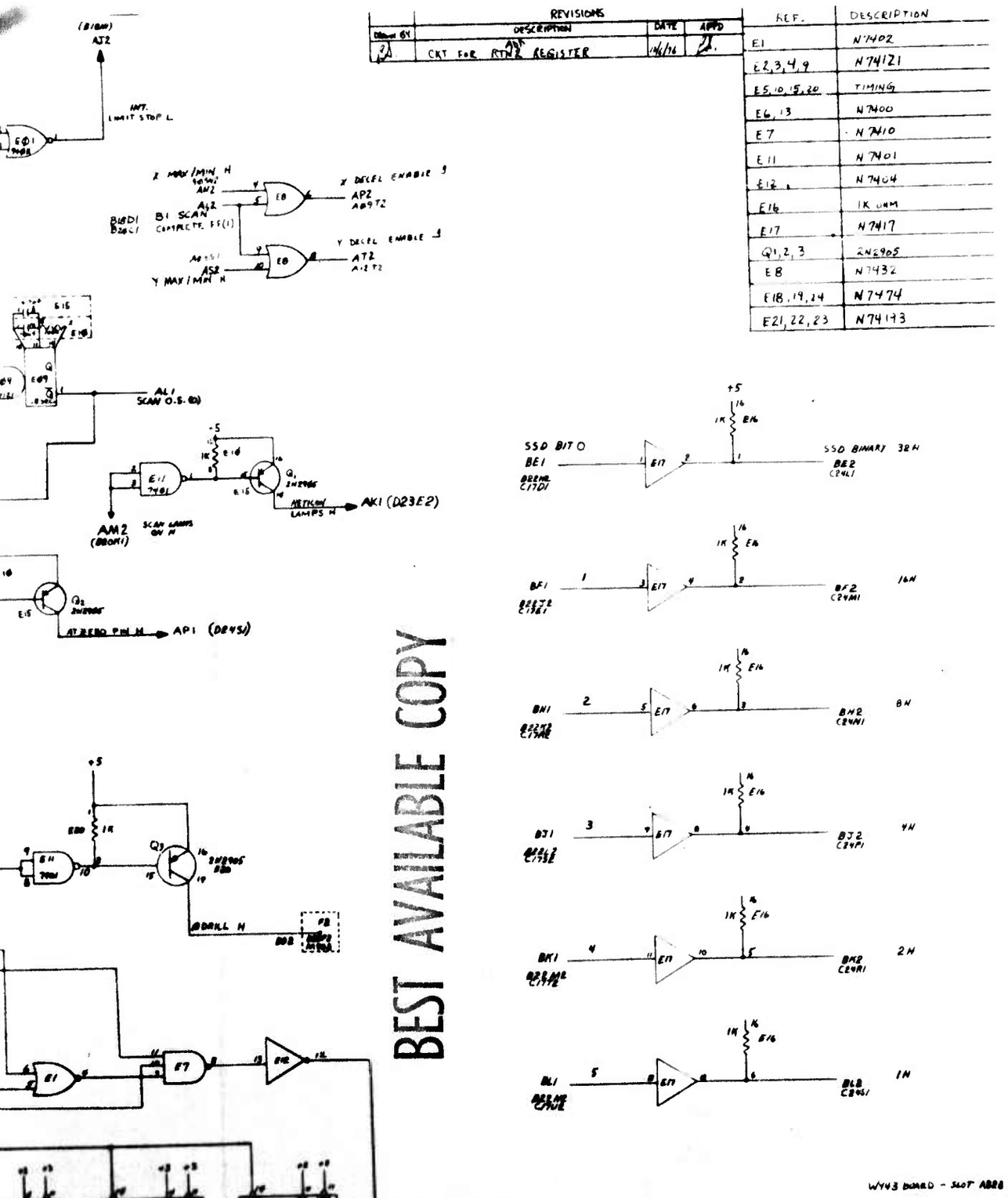
Z AXIS CARD AB25

W975

ALL RESISTORS ¼W EXCEPT AS NOTED

Figure B-20. Z-Axis Control

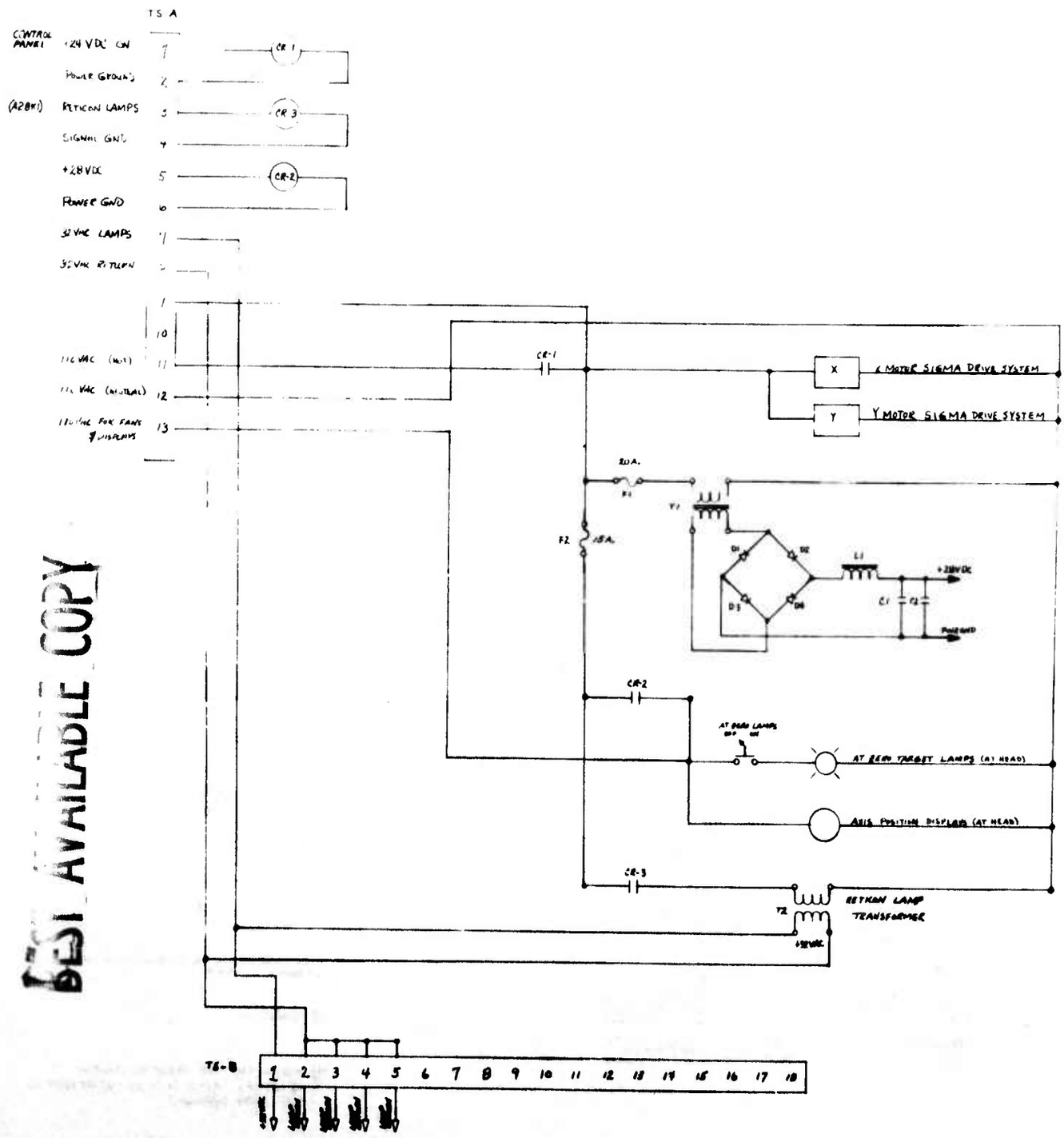

KG16
CD29
FORWARD H
EXTEND O.S
Sol 1 FOR.
BLOCK H
BLOCK O.S
Sol 2 BLOCK
REVERSE H
RETRACT O.S
Sol 3 RET
ROTATE CAMERA H
Sol 4 CAMERA ROTATE
INT. LIMIT STOP L
ALPHA BETA H
SCAN O.S. (D)
SCAN LAMPS ON H
ZERO CYL H
Z LSNC
Z LSNO
Z ENS RING H
Z ENS Position H
DRILL H
B SCAN H
AM1 BRAKE
BYZ DRIVE
RTN Z



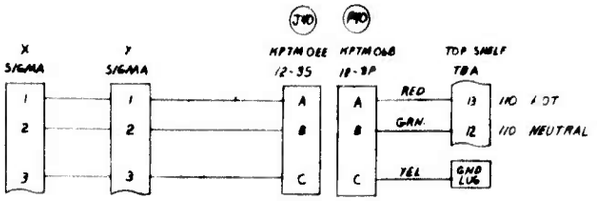
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Figure B-21. RTN 2, SSD, Z-Axis Control, Raticon Lamps, and Camera Rotation

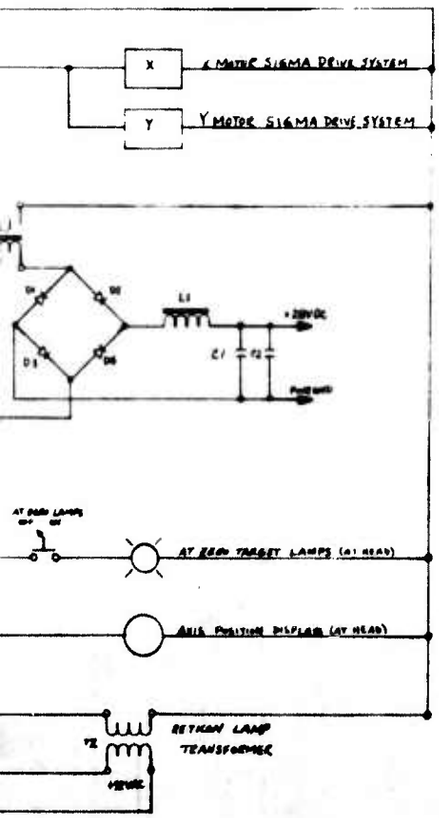
TOP SHELF

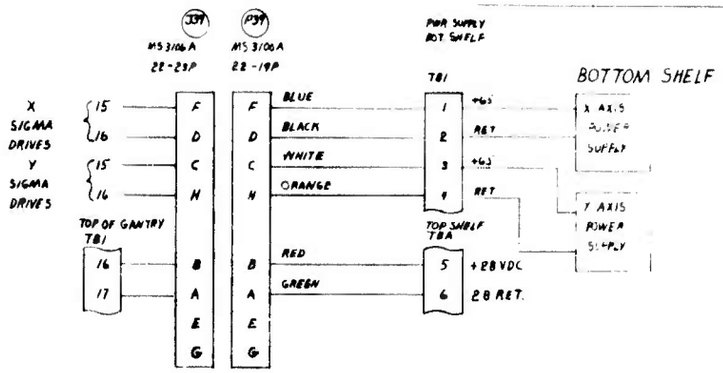


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REF	DESCRIPTION
CR1, CR2, CR3	SOLID STATE RELAY GE
D1, D2, D3, D4	FBL-00-083-LAMBDA
C1, C2	CBL-24-019-LAMBDA
T1	LPTX-2475-2-LAMBDA
T2	RT-204 STANCOR
L1	LPFC-2475-2 LAMBDA





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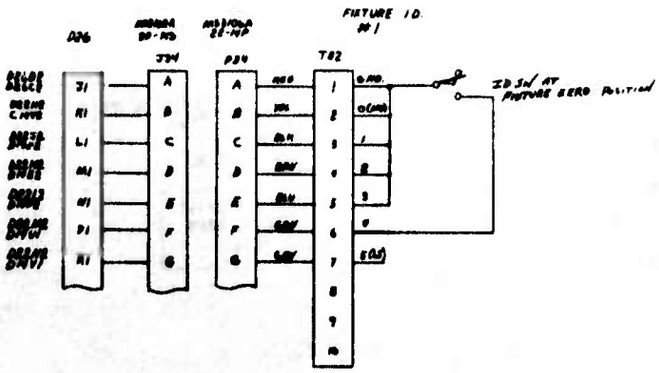
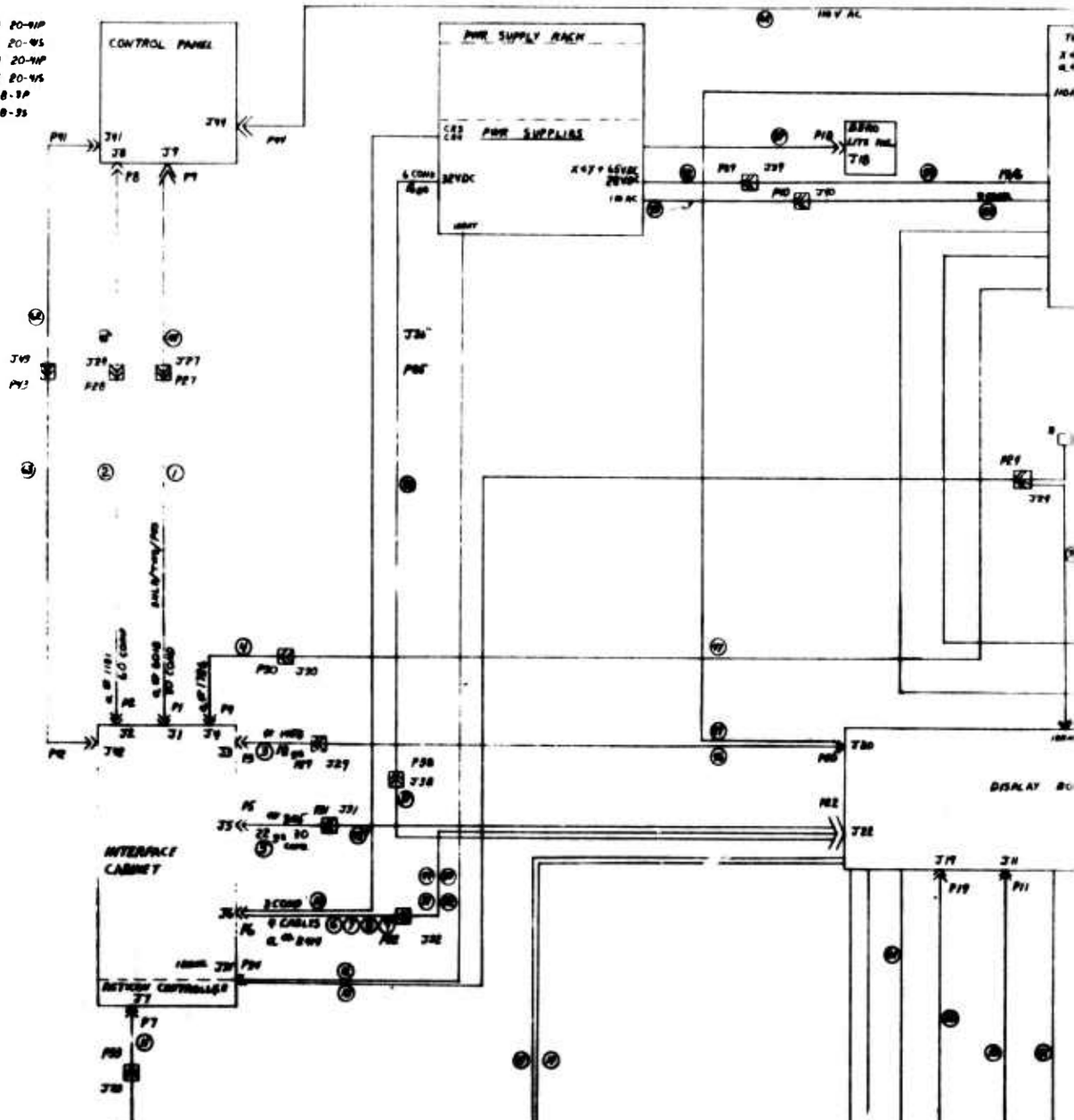


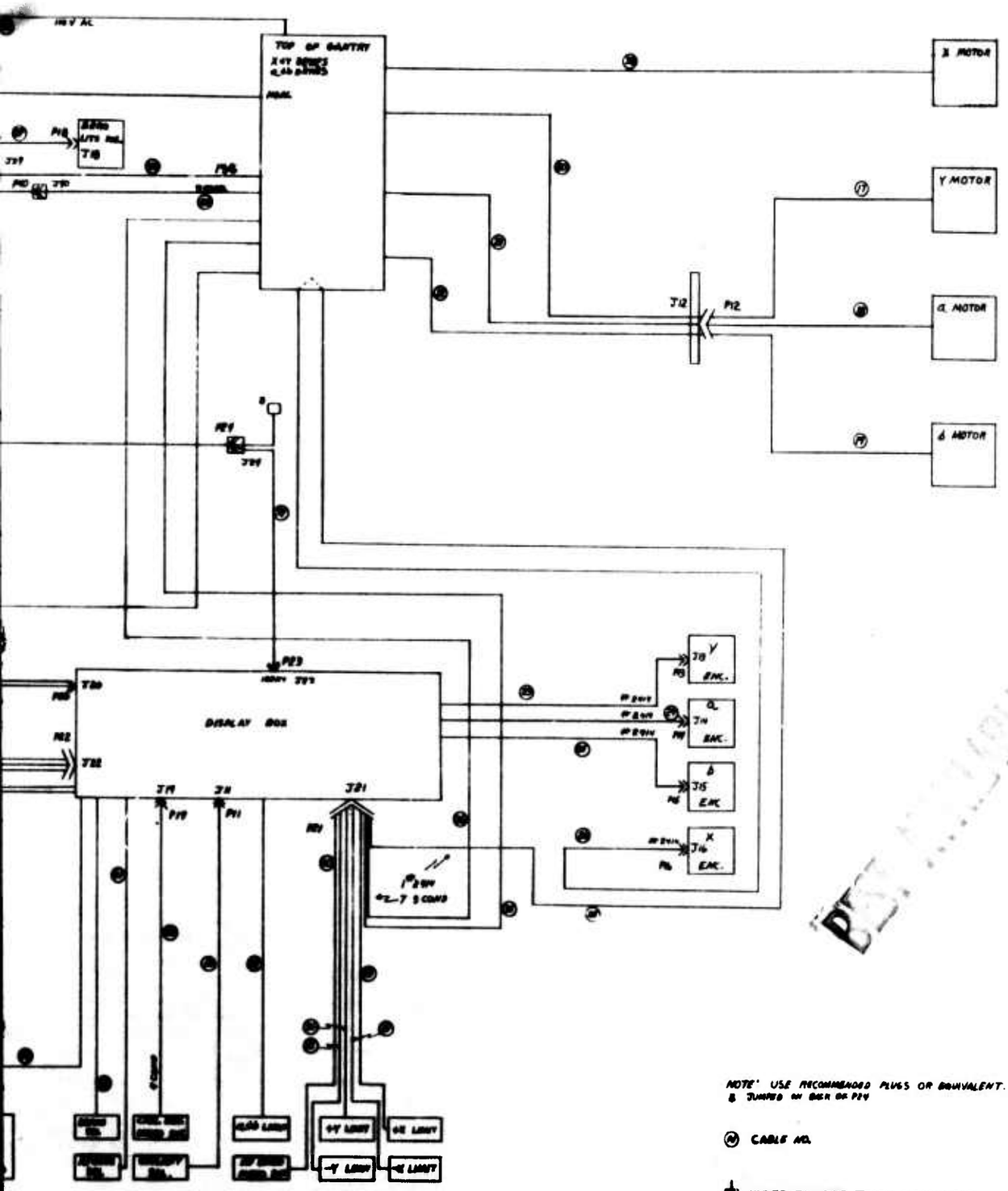
Figure B-22. Power Supply

P1	KPTM 06B 18-32P	P92	KPTM 06B 20-41P
J1	KPTM 02E 18-32S	J92	KPTM 02E 20-41S
P2	MS3126F 24-61P	P93	KPTM 06B 20-41P
J2	MS3126F 24-61S	J93	KPTM 02E 20-41S
P3	KPTM 06B 18-11P	P94	KPT 06B 8-3P
J3	KPTM 02E 18-11S	J94	KPT 02E 8-3S
P4	KPTM 06B 14-19PX		
J4	KPTM 02E 14-19SX		
P5	KPTM 06B 18-32PX		
J5	KPTM 02E 18-32SX		
P6	KPTM 06E 14-19P		
J6	KPTM 02E 14-19S		
P7	KPT 06F 14-18P		
J7	KPT 02E 14-18S		
P8	SPO6CE 24-61S (SR)		
J8	SPO6CE 24-61P		
P9	SPO6CE 22-55S2(SR)		
J9	SPO6CE 22-55P2		
P10	MS3106A 18-1P		
J10	MS3100A 18-1S		
P11	MS3106A 14S-5S		
J11	MS3100A 14S-5P		
P12	MS3108B 24-28P		
J12	MS3102A 24-28S		
P13	CA3106E 18-1S(C)A105		
J13	CA3102E 18-1P		
P14	CA3106E 18-1S(C)A105		
J14	MS3122E 18-1P		
P15	CA3106E 18-1S(C)A105		
J15	MS3122E 18-1P		
P16	CA3106E 18-1S(C)A105		
J16	CA3102E 18-1P		
P17	KPT 06F 14-18S		
J17	KPT 02E 14-18P		
P18	MS3106A 16S-8P		
J18	MS3100A 16S-8S		
P19	MS3106A 14S-5P		
J19	MS3100A 14S-5S		
P20	MS3106A 22-19S		
J20	MS3100A 22-19P		
P21	SPO6CE 22-55S2 (SR)		
J21	SPO6CE 22-55P2		
P22	SPO6CE 24-61S (SR)		
J22	SPO6CE 24-61P		
P23	MS3106B 14S-5P		
J23	MS3100A 14S-5S		
P24	MS 3106A 18-1P		
J24	MS 3106A 18-1S		

P27	KPTM 06B 18-32P		
J27	KPTM 02E 18-32S		
P28	KPTM 06B 24-61P		
J28	KPTM 02E 24-61S		
P29	KPTM 06B 18-11P		
J29	KPTM 02E 18-11S		
P30	KPTM 06B 14-19PX		
J30	KPTM 02E 14-19SX		
P31	KPTM 06B 18-32PX		
J31	KPTM 02E 18-32SX		
P32	KPTM 06B 14-19P		
J32	KPTM 02E 14-19S		
P33	KPTM 06B 14-18P		
J33	KPTM 02E 14-18S		
P34	MS3106A 22-19P		
J34	MS3100A 22-19S		
P35	KPTM 06B 8-3P		
J35	KPTM 02E 8-3S		
P36	KPT 06B 8-6PX		
J36	KPT 02E 8-6SX		

P37	KPTM 06B 14-19P		
J37	KPTM 02E 14-19S		
P38	MS3106A 22-19P		
J38	MS3100A 22-19S		
P39	KPT 06B 8-6PX		
J39	KPT 02E 8-6SX		
P40	MS3106A 22-19P		
J40	MS3100A 22-19S		





NOTE: USE RECOMMENDED PLUGS OR EQUIVALENT.
8 JUMPED ON BOX OR P19

(N) CABLE NO.

HORIZONTAL PWR. TRACK DISCONNECT IS PLACES. J+P23, 24, 25, 26 WILL BE PART OF THE GANTRY DISCONNECT.

Figure B-23. Cabling Diagram

CABLE # (FROM V07 - 1514 - 00)	DEST.	END PREP.	CABLE NO.	# OF COND.	GA.	TYPE	INSL.	LENGTH FT.	END PREP.	DEST.
1	CPU CAB.	P1	a 6018	30	22	TSP		70	J27	GANTRY
2	CPU CAB	P2	a 1181	60	22	S		70	J28	GANTRY
3	CPU CAB.	P3	a 1458	10	18	S		70	J29	GANTRY
4	CPU CAB	P4	a 1726	15	20	S		70	J30	GANTRY
5	CPU CAB.	P5	a 3115	30	22	S		70	J31	GANTRY
6	CPU CAB	P6 (1 OF 5)	B 83399	4	22	S	TEF	70	J32	GANTRY
7	CPU CAB	P6 (2 OF 5)	B 83399	4	22	S	TEF	70	J32	GANTRY
8	CPU CAB	P6 (3 OF 5)	B 83399	4	22	S	TEF	70	J32	GANTRY
9	CPU CAB	P6 (4 OF 5)	B 83399	4	22	S	TEF	70	J32	GANTRY
10	CPU CAB	P6 (5 OF 5)	B 83399	3	22	S	TEF	90	CUT	PWR. RACK
11	CPU CAB	P7	B 9309	18	22	S		70	J33	GANTRY
12	CPU CAB	P34 (1 OF 3)		7			TEF	90	CUT	PWR. RACK
13	CPU CAB	P34 (3 OF 2)		10	22			70	J24	GANTRY
	CYL. FACE	P10								
14	CYL. FACE	J10 (1 OF 2)	B 9773	5	18	S	TEF	8	CUT	DISP BOX
15	CYL. FACE	J10 (2 OF 2)	B 83395	3	22	S	TEF	8	CUT	DISP. BOX
16	DISP. BOX	P11	B 83380	2	20	S	TEF	1	CUT	COOLANT
17	DISC. BKT.	P12 (1 OF 3)	B 8627	4	14	S		3	CUT	Y MOTOR
18	DISC. BKT.	P12 (2 OF 3)	B 9773	6	18	S	TEF	7	CUT	α MOTOR
19	DISC BKT.	P12 (3 OF 3)	B 9773	6	18	S	TEF	7	CUT	δ MOTOR
20	DISC. BKT	J12 (1 OF 3)	B 8627	4	14	S		22	CUT	TOP OF GAN
21	DISC BKT	J12 (2 OF 3)	B 9773	6	18	S	TEF	22	CUT	TOP OF GAN
22	DISC BKT	J12 (3 OF 3)	B 9773	6	18	S	TEF	22	CUT	TOP OF GAN
23	Y ENC.	P13	B 83399	4	22	S	TEF	6	CUT	DISP. BOX
24	α ENC	P14	B 83399	4	22	S	TEF	10	CUT	DISP. BOX
25	δ ENC	P15	B 83399	4	22	S	TEF	10	CUT	DISP. BOX
26	X ENC.	P16	B 83399	4	22	S	TEF	3	CUT	TOP OF GANT
27	⊕ LITE PNL.	P18		3	16			40	CUT	PWR. RACK
28	DISP. BOX	P19	B 8777	5	22	S	TEF	5	CUT	CAM. ROTAT
29	DISP. BOX	P20 (2 OF 2)	B 8618	3	16	S	TEF	80	CUT	TOP OF GANT
30	DISP. BOX	P21 (2 OF 8)	B 83395	3	22	S	TEF	5	CUT	⊕ MICRO S
31	DISP. BOX	P21 (3 OF 8)	B 83395	3	22	S	TEF	8	CUT	+ Y LIMIT
32	DISP. BOX	P21 (4 OF 8)	B 83395	3	22	S	TEF	8	CUT	- Y LIMIT S
33	DISP. BOX	P21 (5 OF 8)	B 83395	3	22	S	TEF	23	CUT	+X LIMIT S
34	DISP. BOX	P21 (6 OF 8)	B 83395	3	22	S	TEF	23	CUT	-X LIMIT S
35	DISP. BOX	P21 (7 OF 8)	B 83395	2	22	S	TEF	20	CUT	TOP OF GANT
36	DISP. BOX	P21 (8 OF 8)	B 83395	3	22	S	TEF	20	CUT	TOP OF GANT
37	DISP. BOX	P22 (7 OF 7)	B 8965	5	18	S	TEF	20	P38	GANTRY DIS
38	TOP OF GANTRY	CUT		4	14			6	CUT	X MOTOR
39	∑ POT	CUT	B 83395	3	22	S	TEF	8	CUT	DISP. BOX
40	BRAKE SOL.	CUT	B 83394	2	22	S	TEF	40	CUT	DISP. BOX
41	α & δ LIMIT RING	CUT	B 83394	2	22	S	TEF	8	CUT	DISP. BOX
42	TOP OF GANTRY	CUT	B 8718 3 CO.	6	12			5	P39	GANTRY DIS
43	PWR. RACK	CUT	B 89394	2	22	S	TEF	90	J90	GANTRY DISC
	PWR. RACK	CUT	B 8979	3	14			50	CABLE ASSEMBLY	AC SOURCE
	PWR. RACK	GND LUG		BRAID				50	GND LUG	GROUND
94	GANTRY DISC.	P27	B 6018	30	22	TSP		20	P9 (1 OF 8)	CONT. PNL
95	GANTRY DISC	P28	B 1181	60	22	S		20	P8	CONT. PNL
96	GANTRY DISC	P29	B 1458	10	18	S		20	P20 (1 OF 8)	DISP. BOX
97	GANTRY DISC.	P30	B 1726	15	20	S		5	CUT	TOP OF GANT
98	GANTRY DISC.	P31	a 3115	30	22	S		80	P22 (1 OF 7)	DISP. BOX
99	GANTRY DISC.	P32	B 83399	4	22	S	TEF	20	P22 (2 OF 7)	DISP. BOX
50	GANTRY DISC.	P32	B 83399	4	22	S	TEF	80	P22 (3 OF 7)	DISP. BOX
51	GANTRY DISC.	P32	B 83399	4	22	S	TEF	80	P22 (4 OF 7)	DISP. BOX
52	GANTRY DISC.	P32	B 83399	4	22	S	TEF	80	P22 (5 OF 7)	DISP. BOX
53	GANTRY DISC.	P33	B 9309	18	22	S		80	P17	CAMERA
54	GANTRY DISC	P34	B 89399	8	22	S	TEF	80	P35	DISP BOX
55	TOP OF GANTRY	CUT	B 83399	4	22	S	TEF	19	P31 (HOME)	SYLP BOX
58	GANTRY DISC.	J38	B 8965	5	18	S	TEF	90	CUT	PWR. RACK
59	GANTRY DISC.	J39	B 8718 3 CO.	6	12	S		90	CUT	PWR. RACK
60	GANTRY DISC.	P40	B 89394	2	22	S	TEF	6	CUT	PWR
61	AT⊕ SOL.	CUT	B 83395	3	22	S	TEF	5	CUT	RACK BOX
62	CONTROL PANEL	P41	a 1181	90	22			20	J33	GANTRY BOX
63	DISC BKT.	P42	a 1451	90	22			70	P35	CPU CAB
64	CONTROL PANEL	P44	B 83339	5	22	S	TEF	22	CUT	TOP OF GANTRY

TH FT.	END PREP.	DEST.	REMARKS
	J27	GANTRY DISC.	GD
	J28	GANTRY DISC.	GD
	J29	GANTRY DISC.	GD
	J30	GANTRY DISC.	GD
	J31	GANTRY DISC.	GD
	J32	GANTRY DISC.	GD
	J32	GANTRY DISC.	GD
	J32	GANTRY DISC.	GD
	J32	GANTRY DISC.	GD
	CUT	PWR. RACK	
	J38	GANTRY DISC.	GD
	CUT	PWR RACK	
	J24	GANTRY DISC	GD PART OF LIGHT ARRAY
	CUT	DISP. BOX	
	CUT	DISP. BOX	
	CUT	COOLANT SOL.	
	CUT	Y MOTOR	
	CUT	α MOTOR	
	CUT	β MOTOR	
	CUT	TOP OF GANTRY	
	CUT	TOP OF GANTRY	
	CUT	TOP OF GANTRY	
	CUT	DISP. BOX	
	CUT	DISP. BOX	
	CUT	DISP. BOX	
	CUT	TOP OF GANTRY	
	CUT	PWR. RACK	PWC THERMACORD
	CUT	CAM. ROTATION	
	CUT	TOP OF GANTRY	
	CUT	Θ MICRO SW.	
	CUT	+Y LIMIT SW.	
	CUT	-Y LIMIT SW.	
	CUT	+X LIMIT SW.	
	CUT	-X LIMIT SW.	
	CUT	TOP OF GANTRY	
	CUT	TOP OF GANTRY	
	P38	GANTRY DISC.	GD
	CUT	X MOTOR	
	CUT	DISP. BOX	
	CUT	DISP. BOX	
	CUT	DISP. BOX	
	P39	GANTRY DISC.	GD
	J40	GANTRY DISC.	GD
	ARM SHIELD	AC SOURCE	GD
	RD LUG	GROUND	GD GROUND STRAP
	P1 (1 of 8)	CONT. PNL.	GD
	P8	CONT. PNL.	GD
	P20 (1 of 2)	DISP. BOX	GD
	CUT	TOP OF GANTRY	GD
	P22 (1 of 7)	DISP. BOX	GD
	P22 (2 of 7)	DISP. BOX	GD
	P22 (3 of 7)	DISP. BOX	GD
	P22 (4 of 7)	DISP. BOX	GD
	P22 (5 of 7)	DISP. BOX	GD
	P17	CAM 20A	GD
	P25	DISP. BOX	GD
	P24 (SPARE)	DISP. BOX	
	CUT	PWR. RACK	GD
	CUT	PWR. RACK	GD
	CUT	RACK	GD
	CUT	DISP. BOX	
	J39	GANTRY DISC	GD
	P26	CPU CAB	GD
	CUT	TOP OF GANTRY	

S SHIELDED
TSP TWISTED - SHIELDED - PAIRS
GD GANTRY DISCONNECT
α ALPHA CABLE
B BELDEN CABLE
NOTE: USE RECOMMENDED CABLE OR EQUIVALENT. INSULATION TO BE TEFLON WHERE POSSIBLE.

Figure B-24. Cabling List

2

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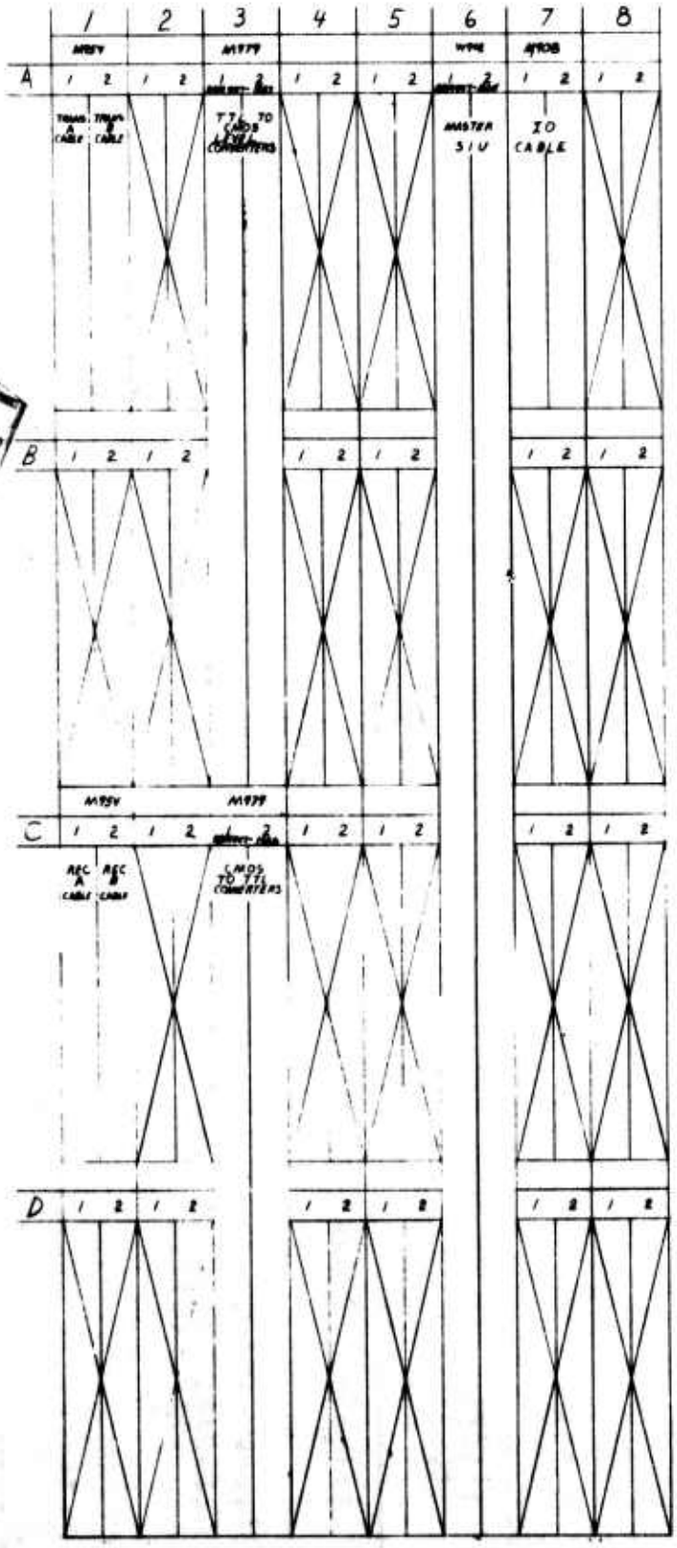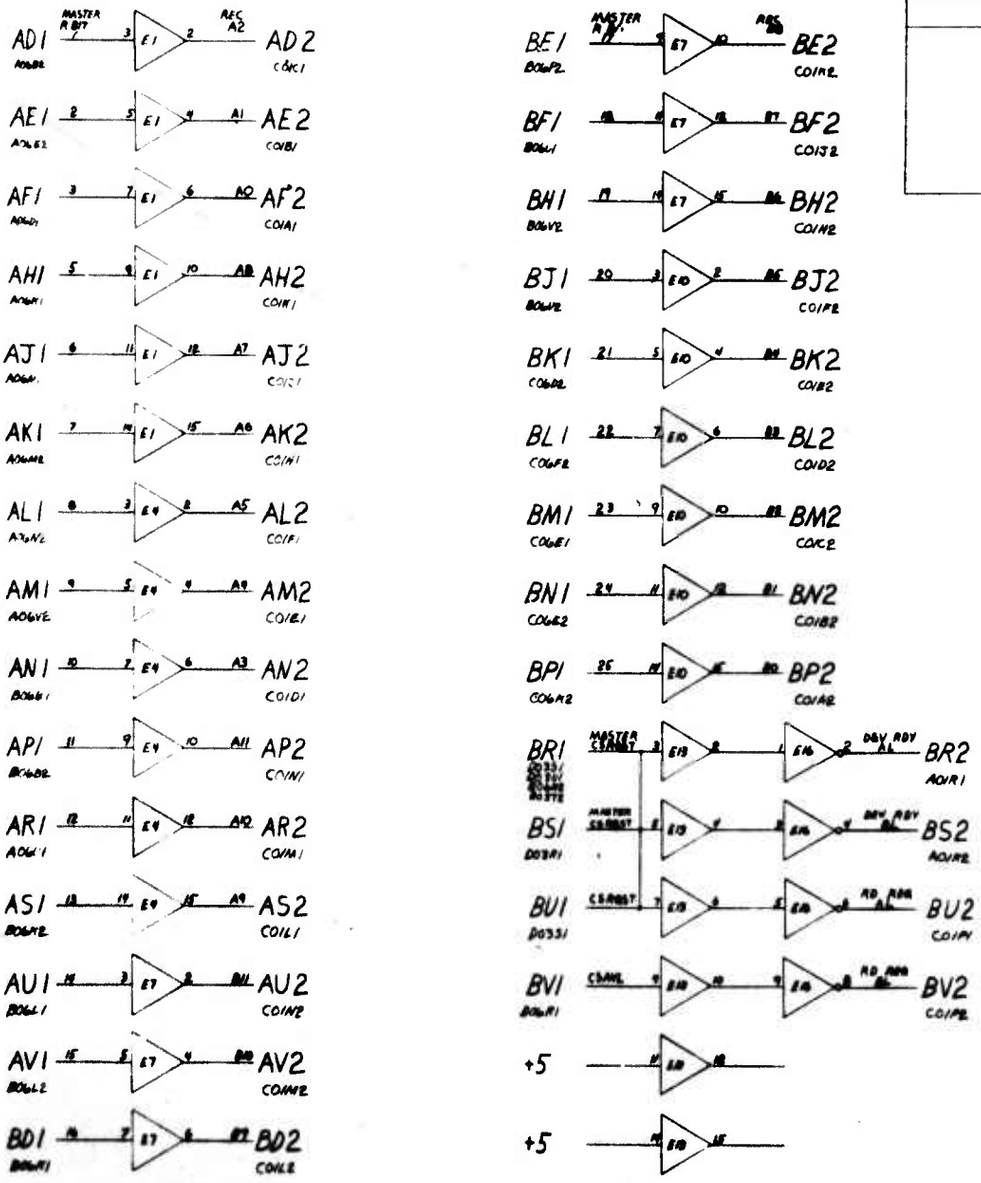


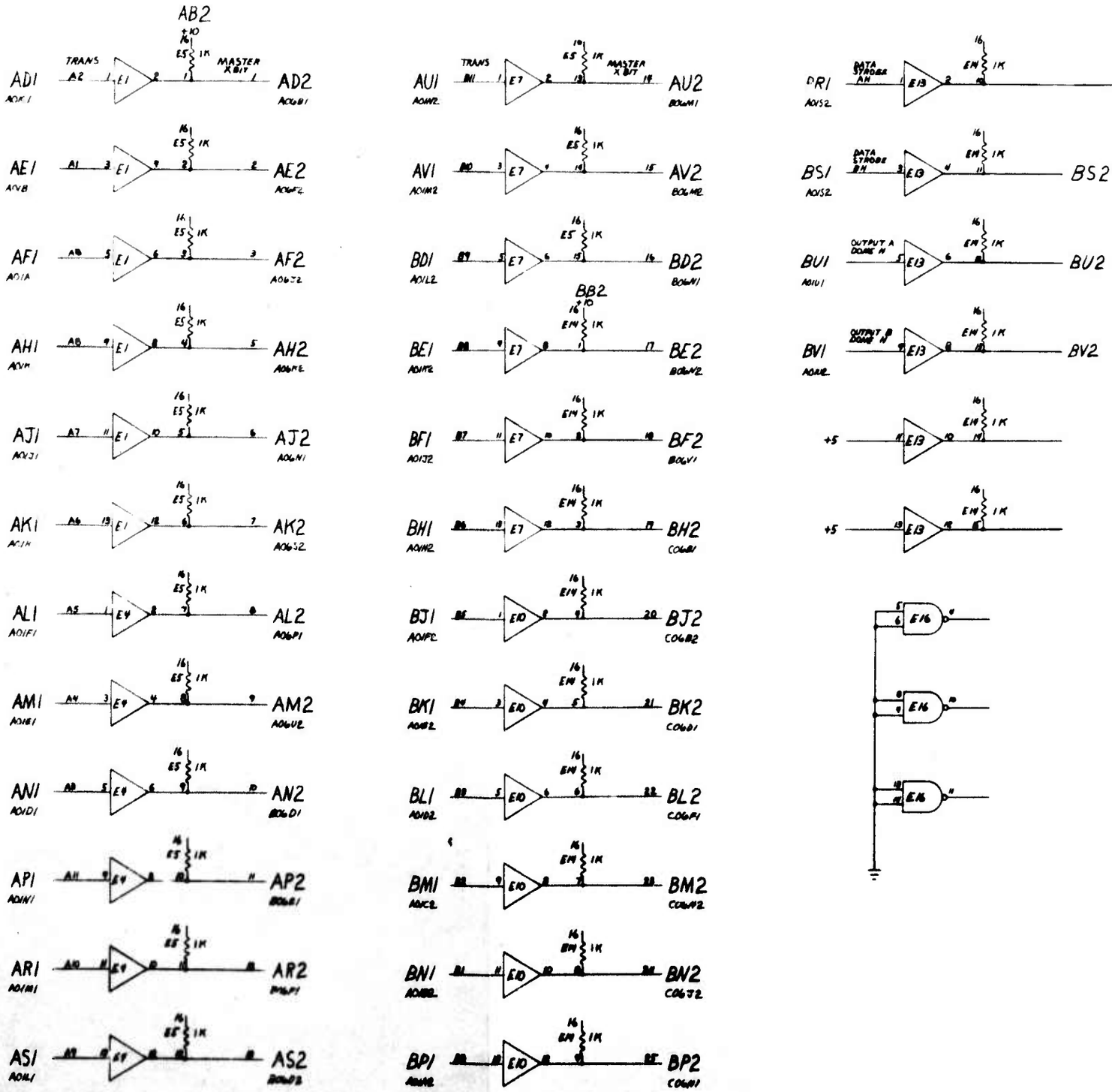
Figure B-25. CPU to SIU Backplane Module Utilization

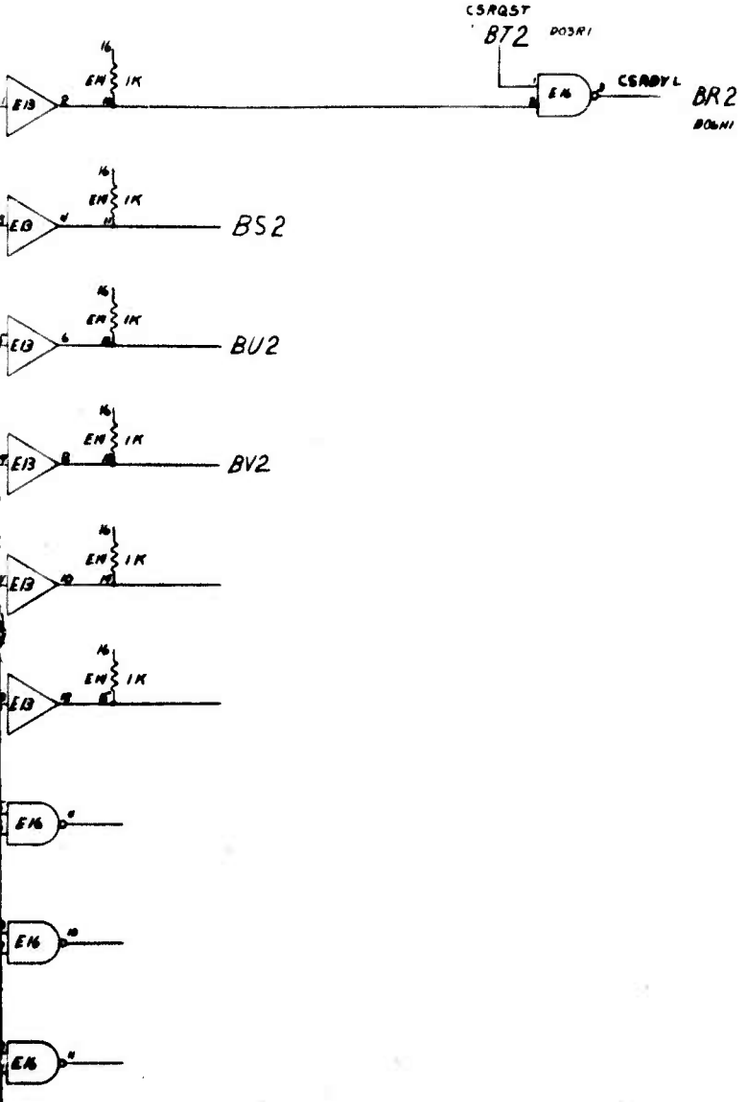
REF.	DESCRIPTION
E1, 4, 7, 10, 13	UD 4050 AE
E16	N7416A



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Figure B-26. CMOS to TTL Level Converters at CPU

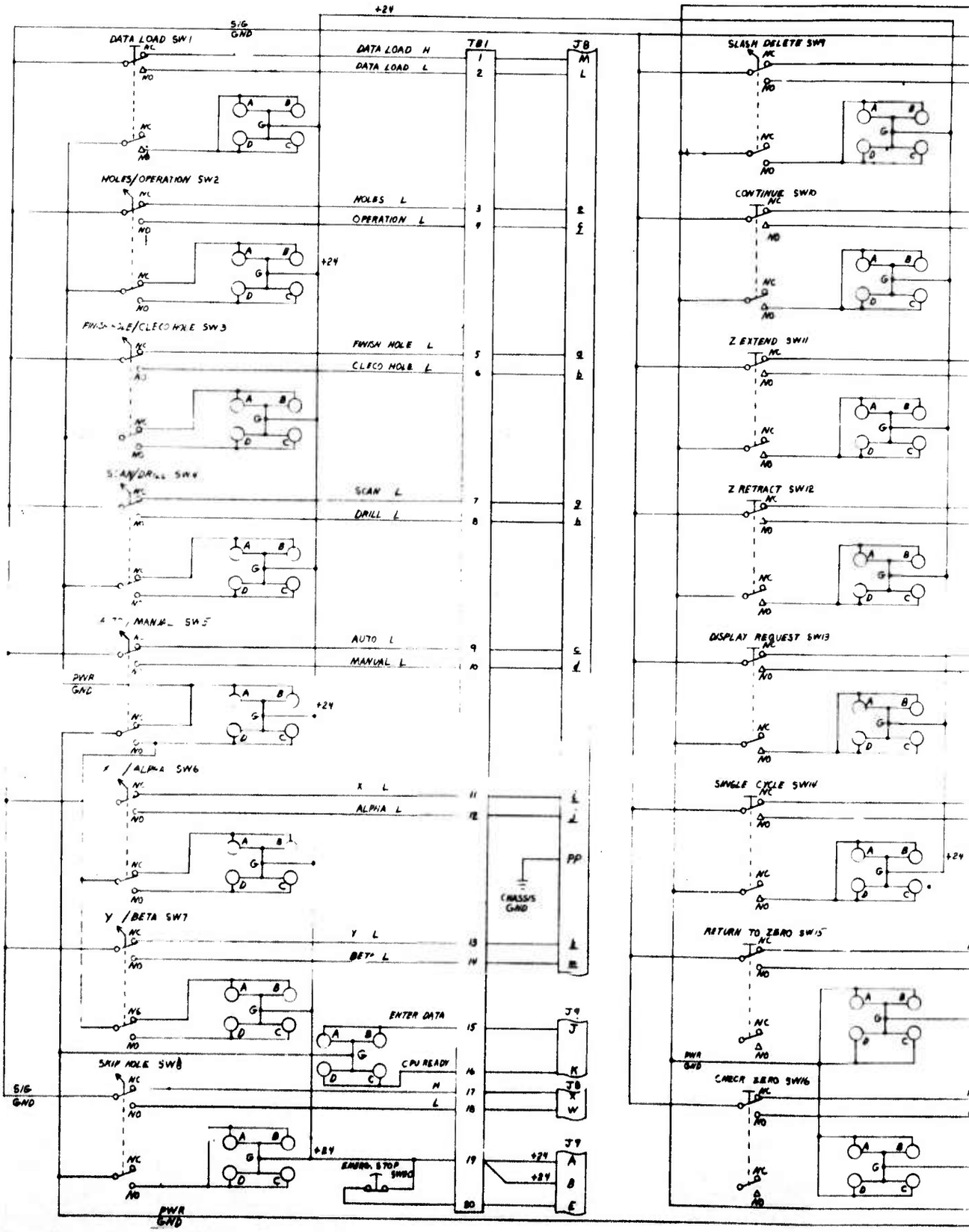

AB2
AD1
AD2
AE1
AE2
AF1
AF2
AH1
AH2
AJ1
AJ2
AK1
AK2
AL1
AL2
AM1
AM2
AN1
AN2
AP1
AP2
AR1
AR2
AS1
AS2
AU1
AU2
AV1
AV2
BD1
BD2
BB2
BE1
BE2
BF1
BF2
BH1
BH2
BJ1
BJ2
BK1
BK2
BL1
BL2
BM1
BM2
BN1
BN2
BP1
BP2
BR1
BS1
BS2
BU1
BU2
BV1
BV2
+5
+5
TRANS
MASTER
DATA STROBE AN
DATA STROBE BN
OUTPUT A DONE N
OUTPUT B DONE N



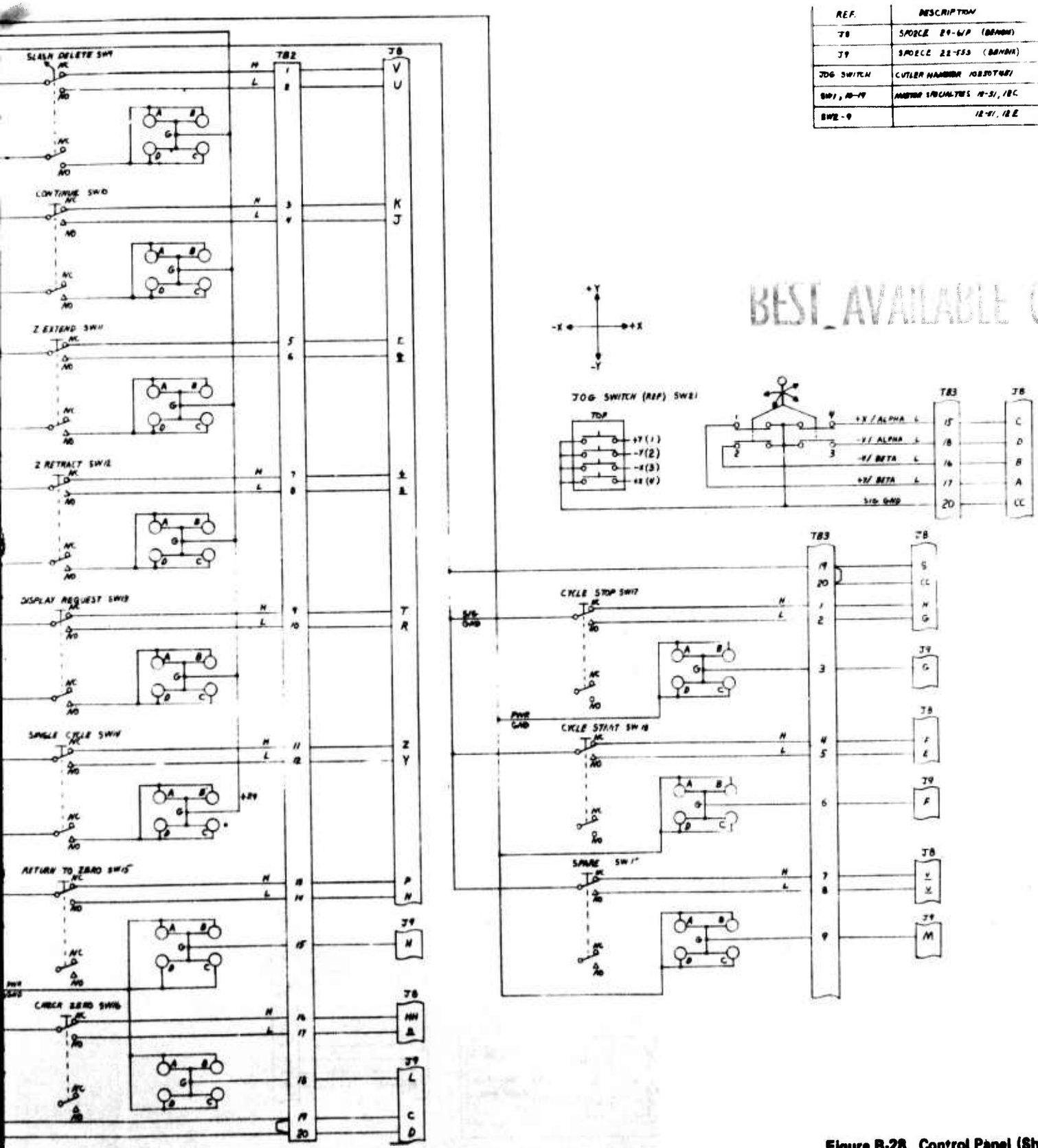
REF	DESCRIPTION
E1, 4, 7, 10, 13	N7417A
E5, 19	9I6C108ASPE
E16	CD40I1AE

Figure B-27. TTL to CMOS Converters at CPU

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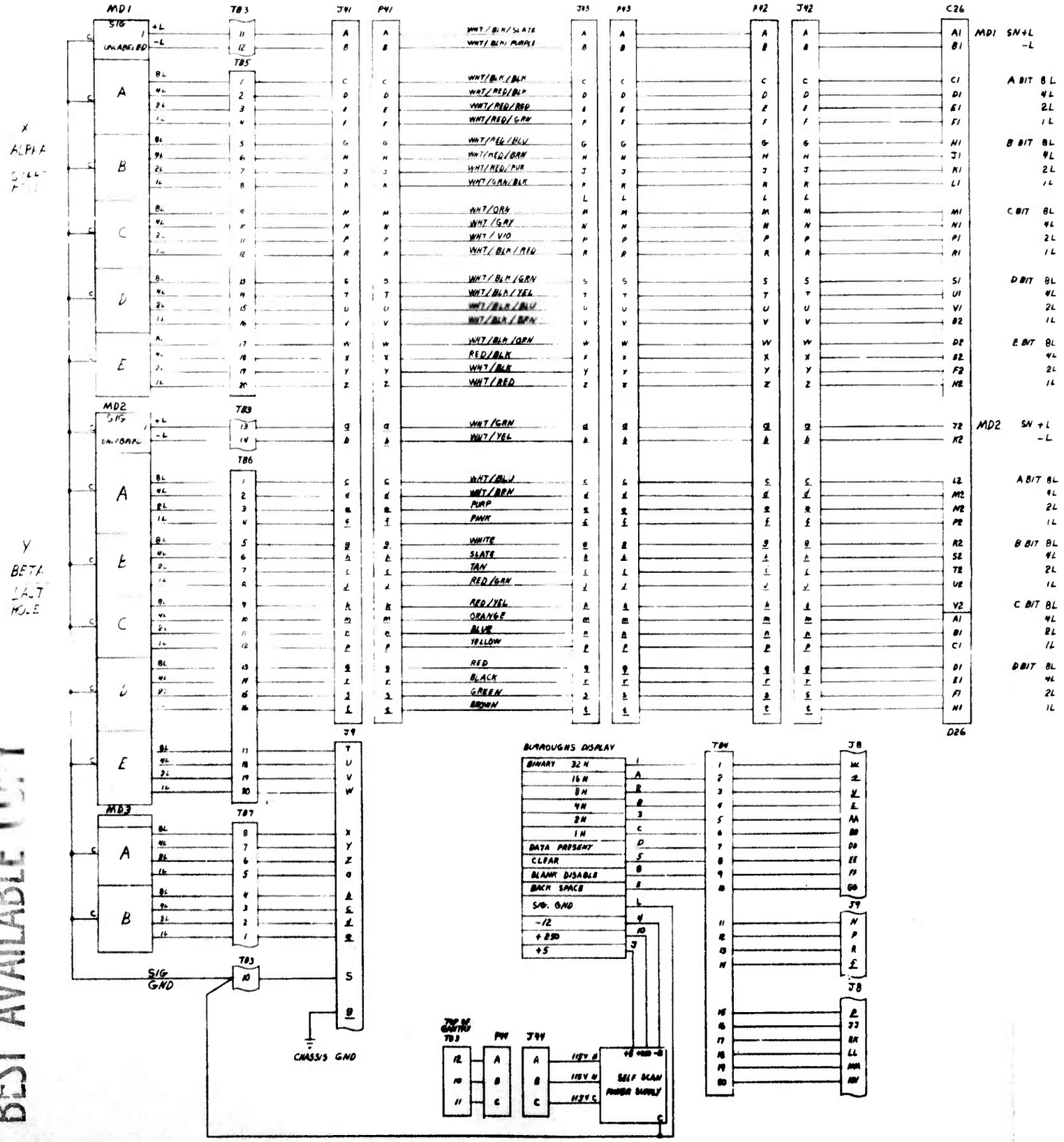


REF.	DESCRIPTION
J8	SPACE 29-6/P (BENDIX)
J9	SPACE 22-55S (BENDIX)
JOG SWITCH	CUTLER HAMMER 10850T681
SW1, 10-19	MICRO SWITCHES 10-51, 18C
SW2-9	12-61, 12E

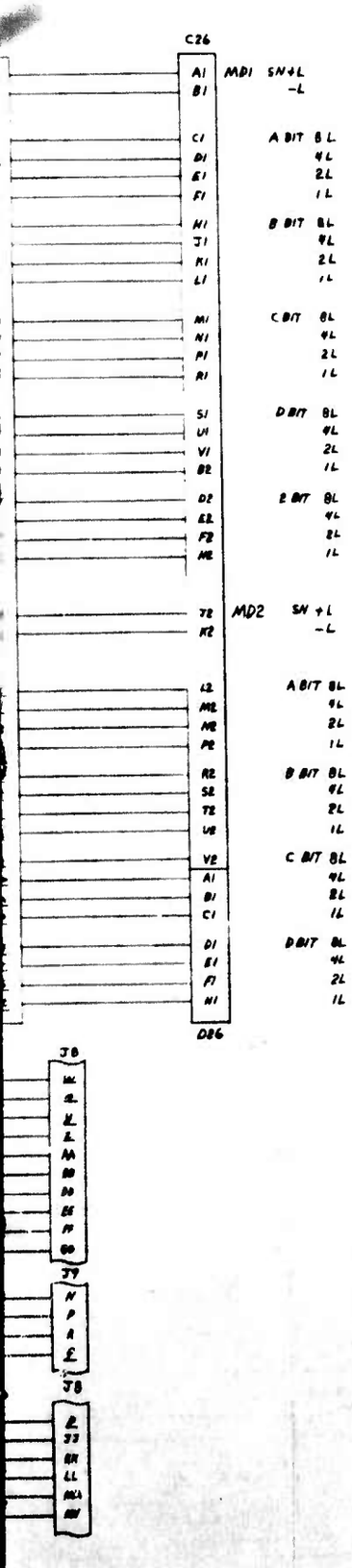


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Figure B-28. Control Panel (Sheet 1 of 3)



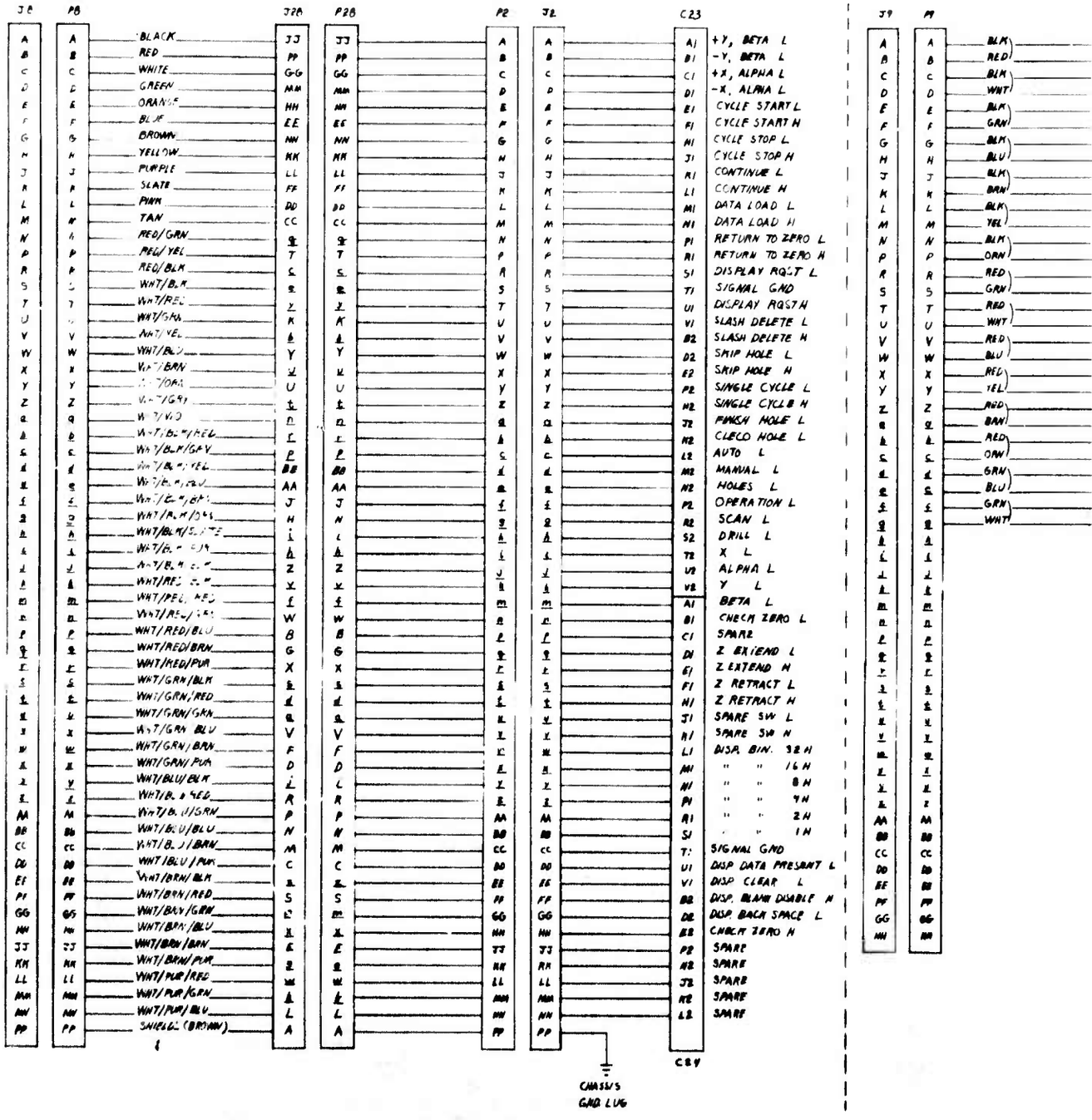
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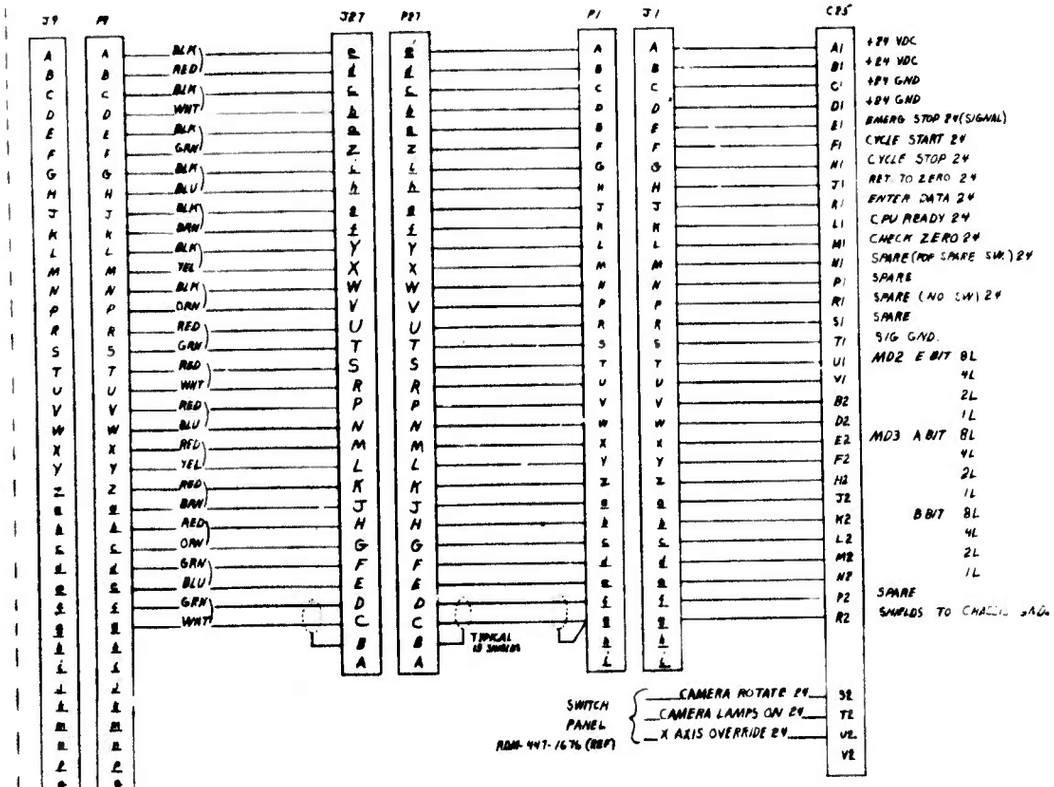


REF	DESCRIPTION
J8	SOURCE 24-61A (BENDIX)
J9	SOURCE 22-183 (BENDIX)
J41	MPTM 02E 20-41S
P41	MPTM 06B 20-41P
J42	MPTM 02E 20-41S
P42	MPTM 06B 20-41P
J43	MPTM 02E 20-41S
P43	MPTM 06B 20-41P
J44	MPT 02E 8-35
P44	MPT 06B 8-35P
DISPLAY	BURROUGHS SSD 0132-0060
PWR SUPPLY	VIKING ELECTRONICS OEM-80A
MD1,2,3 0 to 9	T10-02A CHERRY
MD1,2,3 + & -	T10-99A CHERRY
C26, D26	M908
DISP CONN	SA-127

Figure B-28. Control Panel (Sheet 2 of 3)

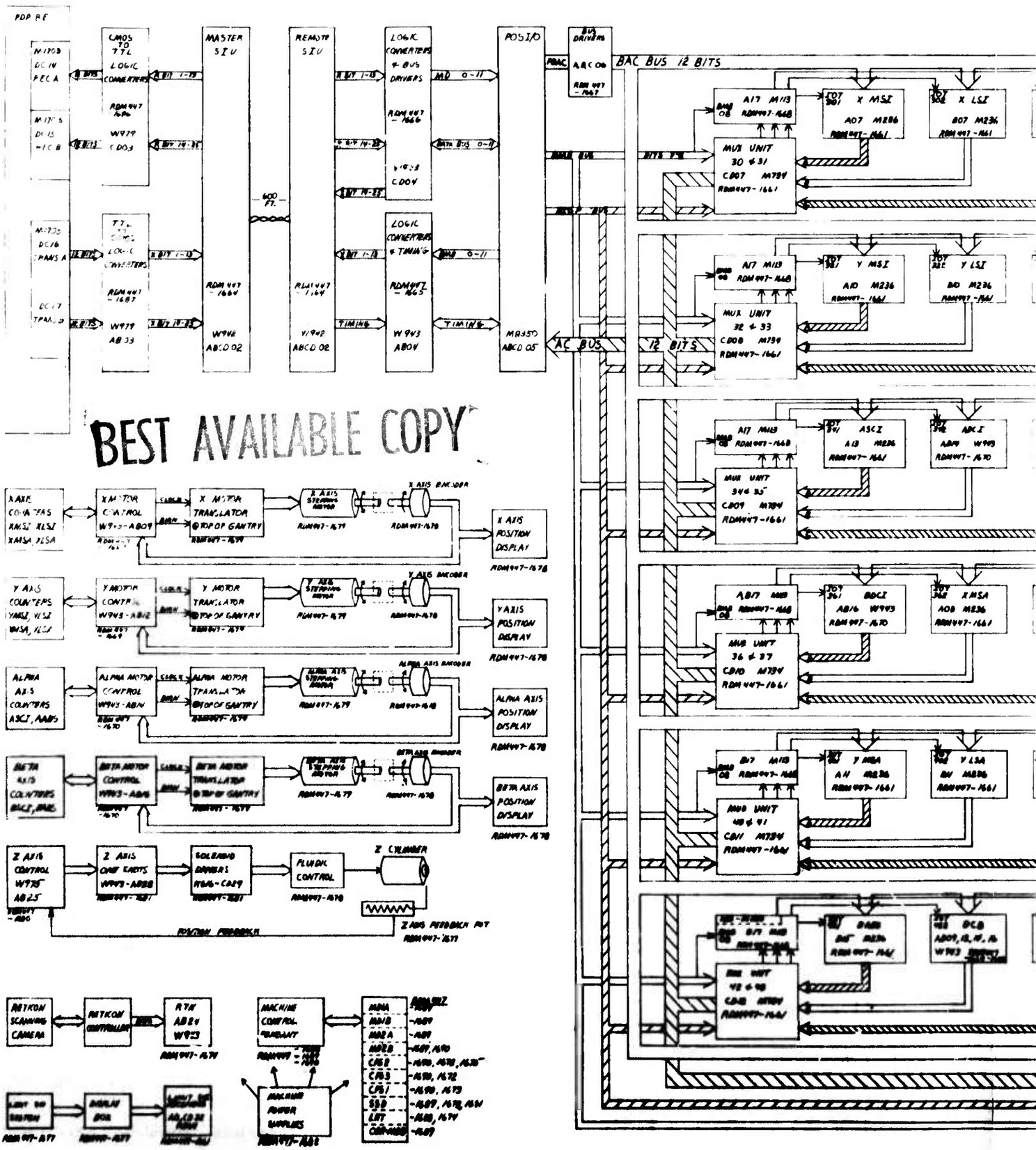
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REF	DESCRIPTION
J1, J27	MPTM 08E 18-32S
P1, P27	MPTM 06B 18-32P
J2	MS3126P 24-61S
P2	MS3126F 24-61P
J28	MPTM 08E 24-61S
P28	MPTM 06B 24-61P
TB1	SP02CE 24-61P
P8	SP06CE 24-61S (SR)
J9	SP08CE 22-55S
P9	SP06CB 22-55SZ(SR)
CB3, CB4, CB5	M908

Figure B-28. Control Panel (Sheet 3 of 3)



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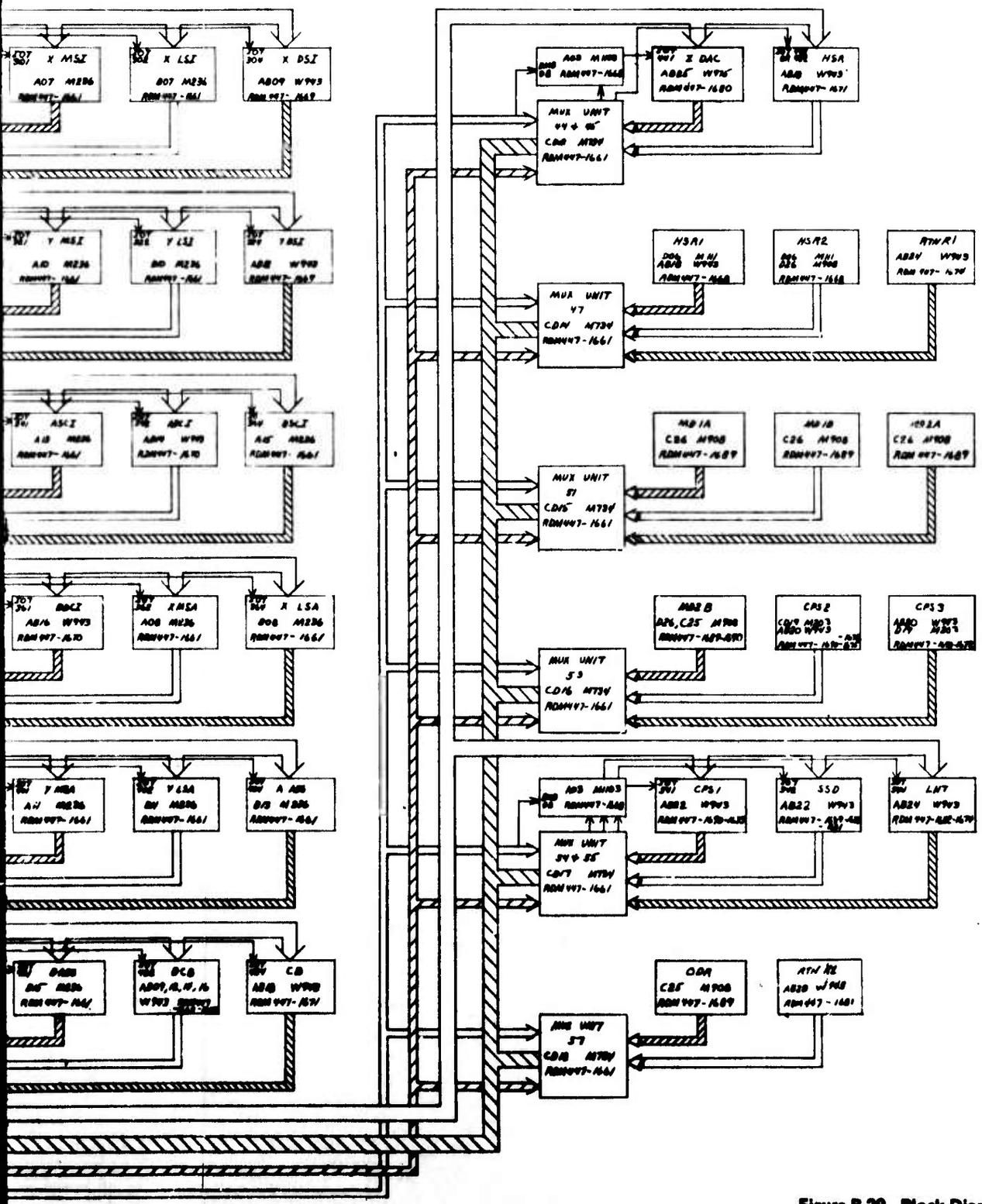


Figure B-29. Block Diagram